TOTAL MAXIMUM DAILY LOADS (TMDLS) FOR THE LITTLE ASSAWOMN BAY AND TRIBUTARIES AND PONDS OF THE INDIAN RIVER, INDIAN RIVER BAY, AND REHOBOTH BAY

Prepared for:

Delaware Department of Natural Resources
and Environmental Control
Division of Water Resources
Watershed Assessment Section
Dover, Delaware

Prepared by:

ENTRIX, Inc.
New Castle, Delaware

J.E. Edinger Associates, Inc.
Wayne, Pennsylvania

ENTRIX Project No. 7057003

November 2004

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1.0 INTRODUCTION

ENTRIX, Inc. (ENTRIX) of New Castle, Delaware and J. E. Edinger Associates, Inc. (JEEAI) of Wayne, Pennsylvania have enhanced the existing hydrodynamic and water quality model called the Generalized Environmental Modeling Surface Water System (GEMSS) to verify the effectiveness of prescribed point and nonpoint source load reductions to meet the Total Maximum Discharge Loads (TMDLs) objectives. The model was originally developed by JEEAI for the Delaware Department of Natural Resources and Environmental Control (DNREC) as part of the Inland Bays Flushing Study (ENTRIX, 2000). The goal of the Flushing Study was to estimate water quality improvements resulting from proposed methods to increase ocean exchange with the Inland Bays. The model has been expanded and enhanced by connecting Rehoboth Bay and Indian River to Little Assawoman Bay via the Little Assawoman Canal, as well as by including connected streams and ponds on the State's 303(d) list of impaired water bodies. The model, a union of 1-dimensional (1-D) streams and the 3-dimensional (3-D) river and bays, was then used to project water quality conditions as a result of point and nonpoint source load reductions.

Description of the TMDL Process

Water quality monitoring and assessment studies suggest high concentrations of nitrogen and phosphorus within the Delaware Inland Bays. These nutrients are essential for both plants and animals of the Inland Bays; however, in large quantities they may negatively impact the ecology of the bays. Some symptoms of nutrient over enrichment are excessive macroalgae growth (sea lettuce and other species), phytoplankton blooms (some potentially toxic), large daily swings in dissolved oxygen (DO) levels, loss of submerged aquatic vegetation (SAV), and fish kills (DNREC, 1998). EPA has mandated that States establish TMDLs under Section 303(d) of the Federal Clean Water Act (CWA) to limit the input of pollutants such as excessive nutrients.

Therefore, DNREC in 1998 adopted a TMDL Regulation for nitrogen and phosphorous for the estuarine portions of the Indian River, Indian River Bay, and Rehoboth Bay (DNREC, 1998). The 1998 TMDL Regulation, which required significant reduction of nutrient loads from point and nonpoint sources, did not include the Little Assawoman Bay or the freshwater streams and ponds which were on the State's 303(d) list of impaired waters. This report will examine the efficacy of the load reductions called for by the 1998 TMDL Regulation for meeting water quality standards in the remaining impaired waters. In addition, the TMDLs for Little Assawoman are established.

Project Scope

The GEMSS model was configured to project water quality that would result if the recommended 1998 TMDL point and nonpoint source load reductions were applied to the entire Inland Bays watershed. Modeled concentrations were compared to water quality standards and nutrient target values. According to Delaware's surface water quality standards, to attain the SAV during growth season (March 1 to October 31), dissolved inorganic nitrogen (DIN) must average 0.14 mg/L as N or below, and average dissolved inorganic phosphorus (DIP) must not exceed 0.01 mg/L as P in tidal portions of the Inland Bays. Furthermore, the State Water Quality Standards require that average dissolved oxygen concentrations not to be below 5 mg/L, and daily minimum values must not be below 4 mg/L for these tidal waters. For freshwater streams and ponds, the State water quality standard for DO is 5.5 mg/l as daily average and 4.0 mg/l as daily minimum. Furthermore, in the streams and ponds, modeled nutrient concentrations were compared to target values for total nitrogen (TN) and total phosphorus (TP).

The GEMSS model was configured to add various species of nutrients together in order to calculate the total and dissolved forms of the nutrients. One assumption that was made to enable these calculations was that dissolved orthophosphate is the principal component of dissolved inorganic phosphorus.

Using GEMSS, the point and nonpoint source nutrient reduction loads prescribed in the 1998 TMDL analysis of the Indian River, Indian River Bay, and Rehoboth Bay (DNREC, 1998), were applied to the entire watershed and water quality effects were examined. As required under the 1998 TMDL report, all nutrient point source loads were reduced to zero. Nutrients, chlorophyll *a*, and dissolved oxygen levels averaged over the critical time period in the streams and ponds within the Inland Bays watershed were compared to target values. Similarly, nutrients and dissolved oxygen concentrations in the tidal portions of the Inland Bays (including Little Assawoman Bay) averaged during the critical time period were compared against standards while chlorophyll *a* was compared against its target values.

The results of the model runs (as will be described later in this report) showed that implementation of the load reductions required by the 1998 TMDL Regulation to the entire watershed would result in achieving all applicable water quality standards and target values.

1.1 Description of the TMDL Process

1.1.1 Indian River and Rehoboth Bays

The interlocked Delaware Inland Bay System includes two main water bodies: Indian River Bay and Rehoboth Bay. Both water bodies are shown in Figure 1-1. The Delaware Inland Bays are located in the southeastern part of the state in Sussex County. The Indian River Bay is connected to the Atlantic Ocean on the east via the Indian River Inlet and to Little Assawoman Bay to the south via the Little Assawoman Canal. Rehoboth Bay is connected to Delaware Bay to the north via the Lewes-Rehoboth Canal and to Indian River Bay to the south. The western portion of Indian River Bay, referred to as the Indian River, terminates at Millsboro Dam.

The drainage area of the system is 55,647 hectares, of which 14,339 hectares is upstream of the impoundment at Millsboro. The basin contains one long-term stream gauging station (USGS Station #01484500) on the Stockley Branch. Mean flow for the period of record (43 years) is 0.196 m^3/sec or 1.44 x 10^{-4} m^3/sec-hectare. Employing the runoff at

Stockley to characterize the remainder of the basin indicates a long-term basin mean flow of 8.03 m^3/sec.

Surface area and volume of the bay system are 7.31 $x10^7$ m^2 and 1.21 x 10^8 m^3, respectively. Mean depth is 1.66 m, which characterizes most of the system. Near the inlet, local mean depth exceeds 10 m. Mean tide range at the inlet is 1.25 m. The tidal prism is $51x10^6$ m^3. The system is well mixed from surface to bottom and is saline virtually throughout its tidal cycle. Median salinity is 22.7 ppt and 95% of observations exceed 4.3 ppt. The lowest salinities occur immediately downstream of the Millsboro Dam during periods of high runoff. Residence time of the system, determined as volume divided by freshwater flow rate, is approximately 174 days. An alternate way to characterize residence time (total volume divided by tidal prism divided by the tidal period) yields a much shorter value: 1.2 days (ENTRIX, 2001). Except near headwaters and in constricted areas in which the tide is dampened, tidal flushing is more effective than runoff in the determination of volumetric flows and mass transport throughout the system.

Historically, the inlet to Indian River Bay has periodically closed completely, and remained closed for more than a year at times, creating a freshwater dominated system. By 1940, the construction of twin parallel jetties resulted in a permanent opening of the inlet approximately 152 m wide and 4.5 m deep. The purpose of this effort was to increase salinity, decrease stagnation, control mosquitoes, and provide a stable navigational waterway. Dredging around the inlet has been repeated periodically through 1990. By 1968, the interior shoreline of the inlet was stabilized to protect against erosion. Inlet scouring has occurred at different rates over the years. Between 1942 and 1974, the mean inlet depth at mean low water deepened from 3.0 m to 7.6 m. However, by 1994, the inlet had scoured to depths ranging from 9.1 m to 33.5 m (Gebert et al., 1992). This scouring has resulted in an increase in the cross-sectional area of the inlet from approximately 84 m^2 to 2880 m^2 between 1939 and 1991 (DIBEP, 1993). From 1939 to 1988, the scouring of the inlet had increased the quantity of water passing through the inlet from approximately 368 cms to 1727 cms (Raney et al., 1990). During this period, freshwater inflow has remained relatively constant, rarely exceeding 8.5 cms (DIBEP, 1993).

In 1951, a channel was dredged extending the entire length of Indian River Bay from the inlet upstream to the base of Millsboro Dam. The channel was dredged to a depth of 2.7 m from the inlet to Old Landing and to a depth of 1.2 m from Old Landing to the base of Millsboro Dam (DIBEP, 1993). Dredging resulted in the removal of over 4.6 million cubic meters of substrate from Indian River Bay between 1937 and 1992. In addition, dredging has been conducted in Indian River Bay to create marinas, artificial lagoons, and provide greater access into the tributaries. These modifications to the inlet and channel have greatly increased salinity intrusion into the estuary and increased tidal flushing throughout the bays (DIBEP, 1993). This flushing has also reduced nutrient levels (i.e., nitrogen) in the lower and middle portions of the bay. However, this flushing has not been adequate to reduce the eutrophic conditions in the upper bay and Rehoboth Bay. The increased influence of marine water has had a direct influence on the biological communities that utilize the middle and upper portions of the bay.

The geological and hydrographical information was obtained from the United States Army Corps of Engineers report (Cerco et al, 1994).

1.1.2 Little Assawoman Bay

Little Assawoman Bay has a surface area of approximately 600 hectares and is located within the State of Delaware (Figure 1-1). It is tidally connected at its southern boundary to the much larger Assawoman Bay, in the state of Maryland. To the north, it is tidally connected to the Indian River Bay through a long navigation canal.

There are two major drainage areas entering Little Assawoman Bay as tributaries, a major wetland area bordering it, and a smaller area of nonpoint source runoff. The major drainage areas are Dirickson Creek (with a drainage area of about 550 hectares to the south), and Miller Creek (with a drainage area of about 40 hectares to the north). An additional major nonpoint source area affecting water quality in Little Assawoman Bay is the Assawoman Wildlife wetlands area. This drainage area is proportionally larger to its adjacent water body surface area than found for the wetlands and tidal flats in Indian River Bay and Rehoboth Bay. The smaller area of nonpoint source runoff is in the southeast corner of the bay near the southern inlet and has about 25 hectares of built-up area extending along the interior beach to the west of U.S. 1.

1.1.3 Impaired Streams

The list of impaired streams from the State's 303(d) list and associated tributaries are listed in Table 1-1. The stream branch numbering listed was used for model organization.

Figure 1-1. Map of the Delaware Inland Bays and Associated Streams

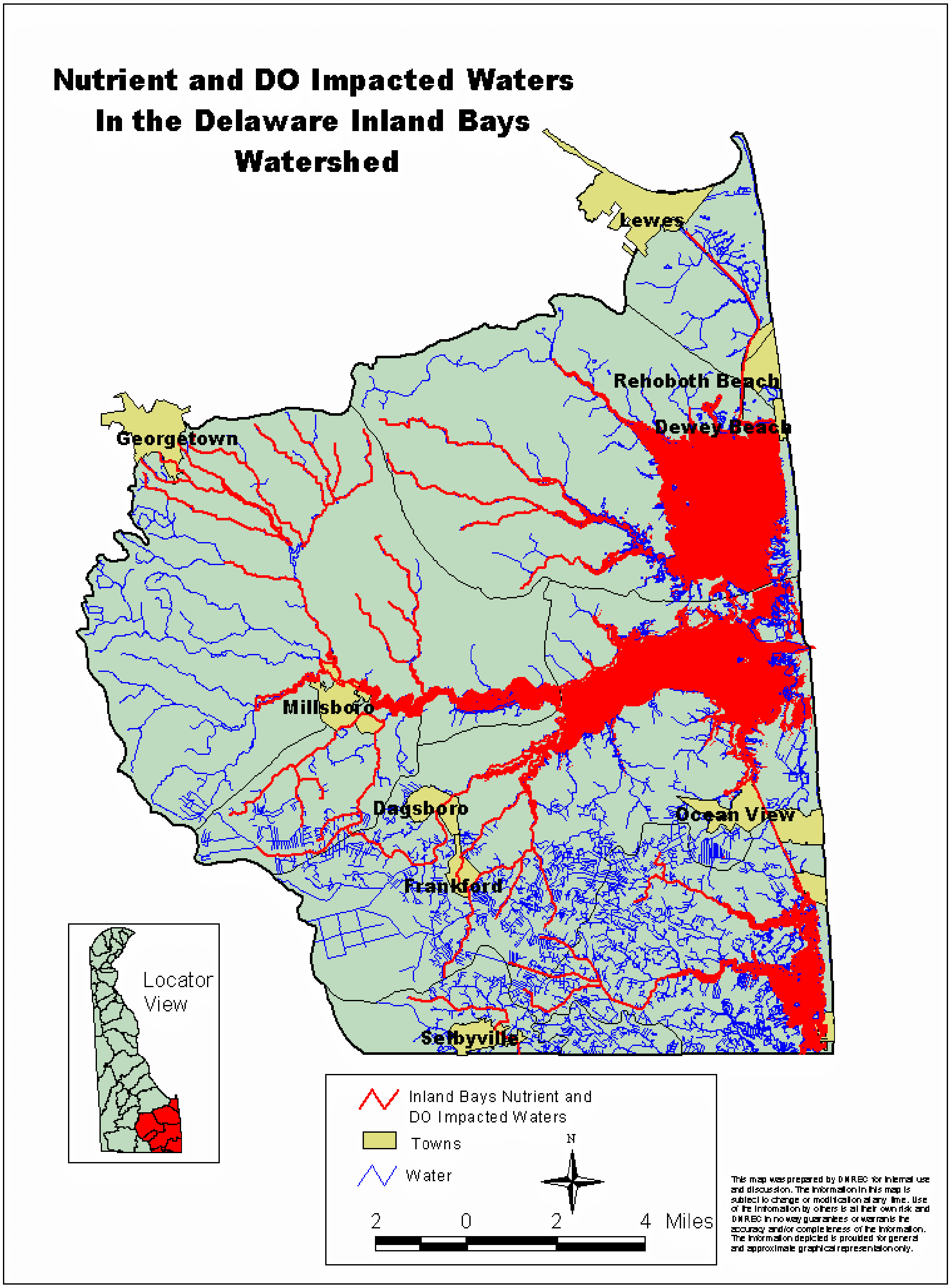


Table 1-1. List of impaired streams and associated tributaries in the Delaware Inland Bays

Stream and branch number	Name
Stream Name 1	***Lewes-Rehoboth Main Canal***
Branch Name 1 – 1	Lewes-Rehoboth Main Canal
Branch Name 1 – 2	Holland Glade
Branch Name 1 – 3	Munchy Branch
Branch Name 1 – 4	Beaver Dam
Branch Name 1 – 5	Wolf Glade
Branch Name 1 – 6	Pot Hook Creek
Branch Name 1 – 7	Cape Henlopen Trib 1
Branch Name 1 – 8	Cape Henlopen Trib 2
Stream Name 2	***Indian River – Little Assawoman Canal***
Branch Name 2 – 1	Indian River - Little Assawoman Canal
Stream Name 3	***Love Creek***
Branch Name 3 – 1	Bundicks Branch/Love Creek
Branch Name 3 – 2	Goslee Creek
Branch Name 3 – 3	Hetty Fisher Glade
Branch Name 3 - 4	Dorman Branch
Branch Name 3 - 5	Arnell Creek
Stream Name 4	***Hopkins Prong – Herring Creek***
Branch Name 4 - 1	Unity Branch
Branch Name 4 - 2	Phillips Branch
Stream Name 5	***Burton Prong – Herring Creek***
Branch Name 5 - 1	Chapel Branch
Branch Name 5 - 2	Sarah Run
Branch Name 5 - 3	Lakewood Branch-Burton Pond Branch 2
Branch Name 5 - 4	Wall Branch
Branch Name 5 - 5	Burton Pond Branch 1
Branch Name 5 - 6	Burton Pond
Stream Name 6	***Swan Creek***
Branch Name 6 - 1	Swan Creek
Branch Name 6 - 2	Longwood Pond Trib
Branch Name 6 - 3	Right Trib of Swan Creek
Branch Name 6 - 4	Left Trib of Swan Creek
Stream Name 7	***Millsboro Pond/Cow Bridge***
Branch Name 7 - 1	Cow Bridge Branch
Branch Name 7 - 2	Stockley Branch
Branch Name 7 - 3	Horse Pound Swamp Ditch
Branch Name 7 - 4	Alms House Ditch
Branch Name 7 - 5	Gills Branch
Branch Name 7 - 6	Walls Ditch
Branch Name 7 - 7	McGee Ditch
Branch Name 7 - 8	McGee Ditch Trib
Branch Name 7 - 9	Eli Ditch

Table 1-1. List of impaired streams and associated tributaries in the Delaware Inland Bays (continued)

Stream and branch number	Name
Stream Name 7	***Millsboro Pond/Cow Bridge***
Branch Name 7 - 10	Peterkins Branch
Branch Name 7 - 11	White Oak Swamp Ditch
Branch Name 7 - 12	Sokorockets Ditch
Branch Name 7 - 13	Welsh Branch
Stream Name 8	***Millsboro Pond/Mirey Branch***
Branch Name 8 - 1	Mirey Branch
Branch Name 8 - 2	Narrow Ditch
Branch Name 8 - 3	Mirey Branch Trib 1
Branch Name 8 - 4	Sheep Pen Ditch
Branch Name 8 - 5	Sheep Pen Ditch - Trib1
Branch Name 8 - 6	Sheep Pen Ditch - Trib2
Branch Name 8 - 7	Sheep Pen Ditch - Trib3
Branch Name 8 - 8	Sheep Pen Ditch - Trib4
Branch Name 8 - 9	Sheep Pen Ditch - Trib5
Branch Name 8 - 10	Sheep Pen Ditch - Trib 6
Stream Name 9	***Millsboro Pond/Long Drain Ditch***
Branch Name 9 - 1	Long Drain Ditch
Branch Name 9 - 2	Shoals Branch
Branch Name 9 - 3	Shoals Branch 2
Branch Name 9 - 4	Shoals Branch 1
Branch Name 9 - 5	Shoals Branch 3
Branch Name 9 - 6	Shoals Branch 4
Branch Name 9 - 7	Shoals Branch 5
Branch Name 9 - 8	Ingram Pond Branch 1
Branch Name 9 - 9	Ingram Pond to Betts Pond
Branch Name 9 - 10	Millsboro Pond Branch 4
Stream Name 10	***Millsboro Pond/Sunset Branch***
Branch Name 10 - 1	Phillips Ditch
Branch Name 10 - 2	Sunset Branch
Branch Name 10 - 3	Phillips Ditch Trib 2
Branch Name 10 - 4	Phillips Ditch Trib 1
Branch Name 10 - 5	Phillips Ditch Trib 3
Branch Name 10 - 6	Sunset Branch Trib 1
Stream Name 11	***Guinea Creek***
Branch Name 11 - 1	Guinea Creek
Branch Name 11 - 2	Guinea Creek Trib 1
Branch Name 11 - 3	Guinea Creek Trib 2
Stream Name 12	***Iron Creek***
Branch Name 12 - 1	Iron Branch
Branch Name 12 - 2	Wiley Branch Ditch
Branch Name 12 - 3	Houston Thorogood Ditch
Branch Name 12 - 4	Iron Branch Trib 1

Table 1-1. List of impaired streams and associated tributaries in the Delaware Inland Bays (continued)

Stream and branch number	Name
Branch Name 12 - 5	Iron Branch Trib 2
Branch Name 12 - 6	Whartons Ditch
Branch Name 12 - 7	Whartons Ditch Trib1
Stream Name 13	***Pepper Creek***
Branch Name 13 - 1	Pepper Creek
Stream Name 14	***Vines Creek***
Branch Name 14 - 1	McCrays Branch
Branch Name 14 - 2	Herring Branch
Branch Name 14 - 3	Vines Creek
Stream Name 15	***Blackwater Creek***
Branch Name 15 - 1	Blackwater Creek
Branch Name 15 - 2	Clarksville
Branch Name 15 - 3	Blackwater Creek - Trib 1
Stream Name 16	***Collins Creek***
Branch Name 16 - 1	Collins Creek
Branch Name 16 - 2	Collins Creek Trib 1
Branch Name 16 - 3	Collins Creek Trib 2
Branch Name 16 - 4	Simon Glade
Stream Name 17	***White Creek***
Branch Name 17 - 1	White Creek
Branch Name 17 - 2	White Creek Trib 1
Stream Name 18	***Miller Creek***
Branch Name 18 - 1	Beaver Dam Ditch
Branch Name 18 - 2	Beaver Dam Ditch Trib 1
Branch Name 18 - 3	Beaver Dam Ditch Trib 2
Branch Name 18 - 4	Beaver Dam Ditch Trib 3
Stream Name 19	***Dirickson Creek***
Branch Name 19 - 1	Bearhole Ditch
Branch Name 19 - 2	Dirickson Creek Trib 1
Branch Name 19 - 3	Dirickson Creek Trib 2
Branch Name 19 - 4	Dirickson Creek Trib 3

1.2 WATER QUALITY STANDARDS AND TARGET VALUES

The model was configured to project water quality that would result if the recommended load reductions under the 1998 TMDL Regulations were applied to the entire Inland Bays watershed. Comparisons were made between applicable standards / target values and modeled concentrations of DIP, DIN, chlorophyll *a*, and DO in the tidal portions of the system (Table 1-2). Table 1-2 lists criteria for bacteria. Though criteria exist, and the model is capable of estimating concentrations of bacteria, modeling the TMDL for bacteria will be addressed at a later date when the bacteria TMDLs are formally established.

To determine benchmarks, Delaware's surface water quality standards were used. According to the standards, to attain the Submerged Aquatic Vegetation (SAV) during growth season (March 1 to October 31):

- average DIN must not exceed 0.14 mg/L as N;
- average DIP must not exceed 0.01 mg/L as P;
- average DO concentrations are not to be below 5.0 mg/L in tidal waters and 5.5 mg/L in the fresh water systems; and
- minimum daily DO values must not be below 4 mg/L.

Though not a standard, chlorophyll *a* was compared against a target value of 20 µg/L. In the streams and ponds, modeled nutrient and chlorophyll *a* concentrations was compared to target values for total nitrogen (TN) and total phosphorus (TP).

Table 1-2. Applicable Water Quality Standards and Target Values for Delaware Inland Bays Watershed

Water body	Water Quality Standard				Water Quality Target Values		
	DO (mg/l)	**DIN-N (mg/l)**	**DIP-P (mg/l)**	**Enterococcus Bacteria (colonies/100 ml)**	**Total N (mg/l)**	**Total P (mg/l)**	**Chl-a (µg/L)**
Tidal portions (Indian River, Indian River Bay, Rehoboth Bay, and Little Assawoman Bay)	5.0 Daily average	0.14	0.01	35 (geometric mean)	1.0	0.1	20
Fresh water systems including streams and ponds	5.5 Daily average	---	---	100 (geometric mean)	3.0	0.2	50

1.3 Load Reductions and Waste Load Allocations

To reach these water quality goals, reductions assessed in the 1998 TMDL Regulation (DNREC 1998) were applied to the entire watershed. These reductions include reductions in point source and nonpoint source nutrients, sediment oxygen demand, and atmospheric loading.

In the 1998 TMDL Report (DNREC, 1998), based on the results of the report's Scenario #69, the recommended reduction of nonpoint source nutrient load reductions range between 40% to 85%, depending on location. This TMDL scenario includes:

- 85% reduction of nonpoint source nitrogen loads from tributaries in the upper Indian River
- 65% reduction of nonpoint source phosphorus from tributaries in the upper Indian River

- 40% reduction of nonpoint source nitrogen from tributaries outside the upper Indian River
- 40% reduction of nonpoint source phosphorus from tributaries outside the upper Indian River
- 20% reduction in atmospheric nitrogen deposition rates
- 100% reduction of nitrogen and phosphorus in all point sources

For this analysis, 40% reduction of N and P were applied to the remaining areas of the watershed that were not included in the 1998 TMDL report (e.g. tributaries to Little Assawoman).

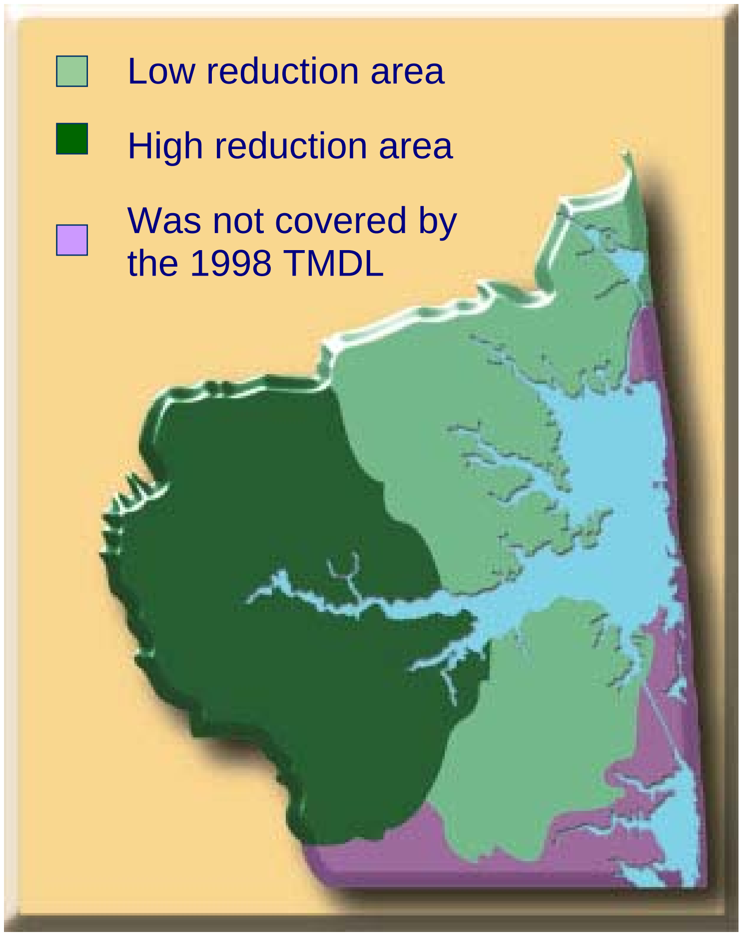
1.3.1 Nonpoint Sources

The 1998 report divides the tributaries into 12 major branches, including five describing the upper Indian River. Using the GEMSS model's designation of streams and branches (Table 1-1), the upper Indian River is comprised of:

- Stream 6: Swan Creek
- Stream 7: Millsboro Pond - Cow Bridge
- Stream 8: Millsboro Pond - Mirey Branch
- Stream 9: Millsboro Pond - Long Drain Ditch
- Stream 10: Millsboro Pond - Sunset Branch
- Stream 12: Iron Creek
- Stream 13: Pepper Creek
- Stream 14: Vines Creek

As described in detail in the Enhancement and Expansion of Hydrodynamic and Water Quality Modeling System Report (ENTRIX, 2004), the nonpoint source loads of nitrogen and phosphorus were estimated through the USGS HSPF model (Gutiérrez-Magness and Raffensperger, 2003). The model examined the nature of the land-use in the watersheds and the conditions of manure / fertilizer application to derive estimates of nutrient runoff. In drainage areas where the USGS model produced highly unrealistic results, the nonpoint source load was back calculated using the water quality measurements taken along the stream.

Figure 1-2. Nonpoint Source Load Reduction Areas



1.3.2 Point Sources

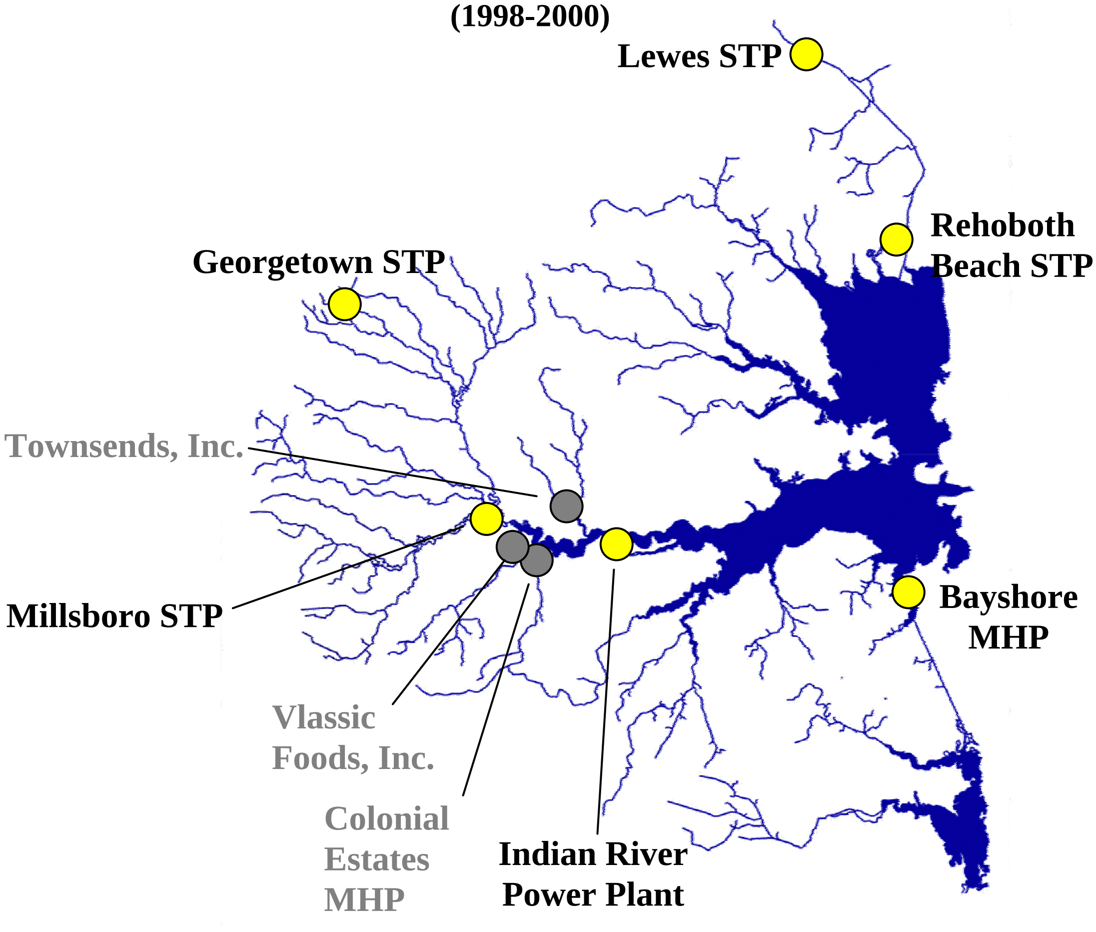
The 1998 TMDL report lists 13 active NPDES point sources that were discharging during the time of the study (1988 - 1990). Point source waste load allocations are applied in this model to nine permitted facilities (Table 1-3) that were discharging during this study's modeling period (1998 - 2000). These facilities each must reduce their nitrogen and phosphorus loads 100%.

It should be noted that of the nine point sources active during 1998-2000, some of the facilities are no longer permitted dischargers. Townsends, Inc. became Mountaire Farms, and subsequently the permit was voided in September of 2001. The permit for Colonial Estates Mobile Home Park was voided in February of 2002. Also, it should be noted that NRG Energy has purchased the Indian River Power Plant from Conectiv, and has renamed it the Indian River Generating Station. Vlassic Food is now Pinnacle Foods, and for the sake of modeling produces essentially no nutrient discharge due to nutrient trading.

Table 1-3. Point Source Dischargers included in the Inland Bays TMDL model

Facility Name	NPDES ID
Bayshore Mobile Home Park	DE0050750
Colonial Estates Mobile Home Park	DE0020061
Georgetown Sewage Treatment Plant	DE0020257
Indian River Power Plant	DE0050580
City of Lewes Sewage Treatment Plant	DE0021512
Rehoboth Beach Sewage Treatment Plant	DE0020028
Millsboro Sewage Treatment Plant	DE0050164
Townsends, Inc.	DE0000086
Vlassic Foods Inc.	DE0000736

Figure 1-3. Point Sources Locations Active during TMDL Model Period (1998-2000)

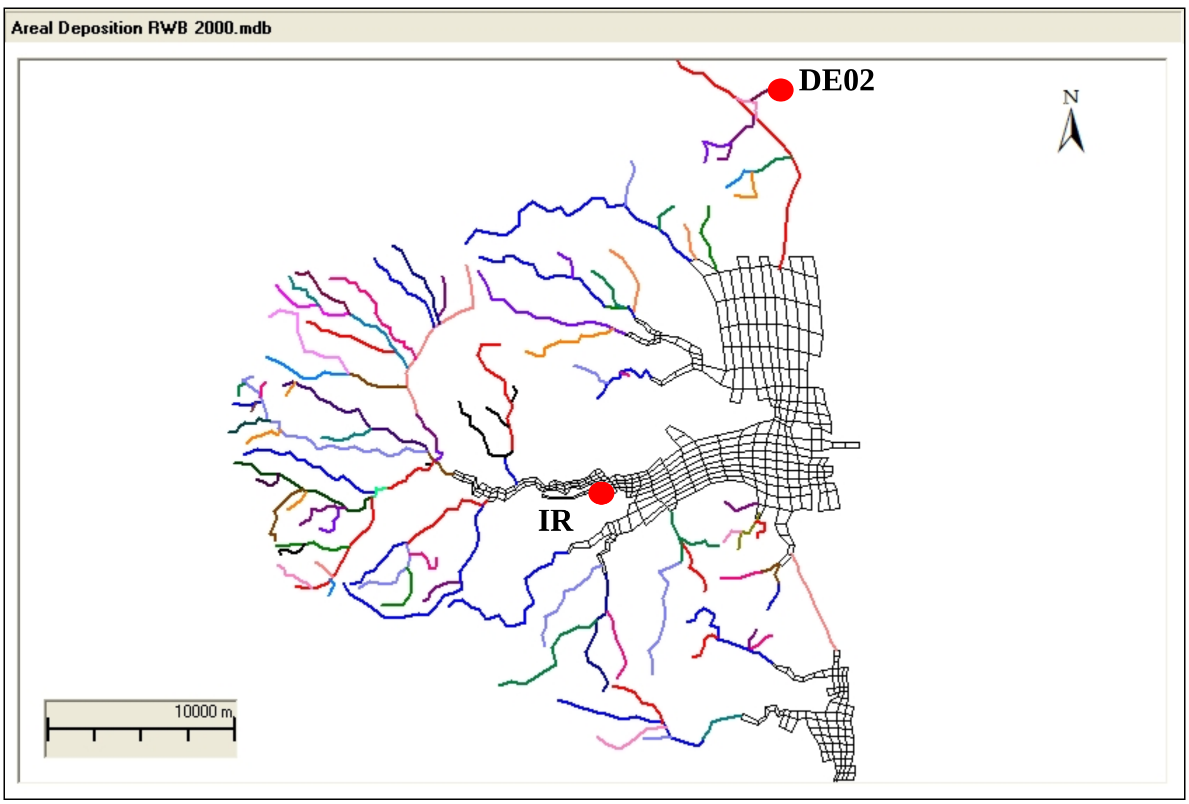


Note: NPDES permits have since been voided for locations shaded gray.

1.3.3 Atmospheric Deposition

Atmospheric nitrogen deposition was applied to the Inland Bays model. According to the 1998 TMDL (DNREC, 1998), the atmospheric nitrogen loads were applied uniformly to the open surfaces of the Indian River, Indian River Bay, and Rehoboth Bay. In this model, the load was also uniformly applied to Little Assawoman Bay. Based upon the time series of nitrogen atmospheric loadings provided in a report by Joseph Scudlark for the Center of Inland Bays (Scudlark, 2002), data was collected at the long-term NADP/AIRMoN station DE02 at Cape Henlopen, and station IR located on the Indian River approximately 14 miles southwest (Figure 1-4). Measurements were made for NH_4^+ and NO_3^-. The model calculated a total nitrogen load using these values multiplied by the associated rainfall intensity to calculate areal loads. To best estimate the loads across the surfaces of the Inland Bays, a non-linear interpolation method was applied to the depositional data at the two stations. The average load rate during wet weather was based upon time varying data from which yielded loads averaging 765 kg/d. Atmospheric loads of phosphorus were considered insignificant, as the 1998 TDML study cited monitoring data at Cape Henlopen yielded no detectable levels of atmospheric deposition.

Figure 1-4. NADAP/AIRMON Stations Used for Nitrogen Atmospheric Deposition



2.0 DESCRIPTION OF GEMSS

The models being used in this analysis are the hydrodynamic and transport (HDM) and the WQM of the GEMSS (Kolluru, 1999), which is an integrated system of 3-D hydrodynamic and transport models embedded in a geographic information and environmental data system (GIS), grid generator and editor, control file generator, 2-D and 3-D post processing viewers and additional tools that include a meteorological data processor, and a USGS flow data processor to support 3-D modeling. Customization of the suite of hydrodynamic, transport and water quality models is achievable through the use of a modular design reflecting the needs of each user's application.

The GEMSS software uses GLLVHT (Generalized, Longitudinal-Lateral-Vertical Hydrodynamic and Transport), which is a state-of-the-art three-dimensional numerical model that computes time-varying velocities, water surface elevations, and water quality constituent concentrations in rivers, lakes, reservoirs, estuaries, and coastal water bodies. The computations are done on a horizontal and vertical grid that represents the water body bounded by its water surface, shoreline, and bottom. The water surface elevations are computed simultaneously with the velocity components. The water quality constituent concentrations are computed from the velocity components and elevations. Included in the computations are boundary condition formulations for friction, wind shear, turbulence, inflow, outflow, surface heat exchange, and water quality kinetics. The model can be used to analyze system dynamics and to predict the impacts of actual events or possible design or management alternatives. The complete technical document on GEMSS can be obtained from JEEAI's web site www.jeeai.com.

The theoretical basis of the three-dimensional GLLVHT model was first presented in Edinger and Buchak (Edinger and Buchak, 1980) and subsequently in Edinger and Buchak (Edinger and Buchak, 1985). The GLLVHT model has been peer reviewed and published (Edinger and Buchak, 1995; Edinger et al. 1994 and 1997; Kolluru et al., 1999; and Edinger and Kolluru, 1999). The fundamental computations are an extension of the well-known longitudinal-vertical transport model (GLVHT) that was developed by J. E. Edinger Associates, Inc. beginning in 1974 and summarized in Buchak and Edinger (Buchak and Edinger, 1984). This model forms the hydrodynamic and transport basis of the Corps of Engineers' water quality model CE-QUAL-W2 (U. S. Army Engineer Waterways Experiment Station, 1986).

Several different models may be chosen for the WQM, depending on the complexity required and data available. The model chosen for this analysis is the WQDPM model. WQDPM is an extension of EPA's EUTRO5 model, and includes both dissolved and particulate forms of nitrogen, phosphorus, and CBOD, as well as dissolved oxygen, organic carbon, and phytoplankton. WQDPM is linked and run simultaneously with the HDM module of GEMSS on the same grid.

3.0 TMDL MODELING

3.1 THE CALIBRATED MODEL

The GEMSS model was constructed using inputs from 1998 through 2000, the time period with the greatest spatial and temporal coverage of recent field measurements available for the Inland Bays. Model inputs were compiled for bathymetry, freshwater flows, point source discharges, tidal elevations and currents, atmospheric deposition, and sediment fluxes. Water quality data were gathered from a variety of sources including DNREC's seasonal water quality measurements (residing in EPA's STORET database), measurements taken by DNREC's Pfiesteria Study, the Citizen's Monitoring Group, the University of Delaware's (UD's) CISNet database, stormwater monitoring, and special surveys conducted by DNREC and UD for additional tide and current data. Estimates of nonpoint source nutrient runoff was provided by the US Geological Society (USGS) from the HSPF Model (Gutiérrez-Magness and Raffensperger, 2003). The consolidated 1-D non-tidal and 3-D tidal models were calibrated using 1999, the year with greatest coverage of data throughout the year. Calibrations were performed for tidal elevations, water temperatures, salinity, and water quality. The model was then verified for the year 2000. Extensive error analysis conducted for the hydrodynamic model showed good model calibration. Model predicted water quality concentrations at selected 50 stations in the Inland Bays for all the years show reasonable comparison with the available limited forcing data (time varying loads) for the model.

The GEMSS model was updated to include time varying non point source loadings computed for the Inland Bays using the HSPF model. A complete set of control files for the year 1999 was created using the HSPF model output data and the use of available field data for missing time periods in the HSPF model outputs.

Specific details about the GEMSS-HDM, GEMSS-WQM, and the model calibration can be found in the GEMSS Enhancement and Expansion Report (ENTRIX, 2004).

After the initial calibration, two other factors became evident and required adjustments to reach a final calibrated state: extreme values for chlorophyll *a* and DO.

Based on historical sampling, maximum values of chlorophyll *a* typically range between 100 µg/L to 200 µg/L in the Inland Bays. A few unusually high chlorophyll *a* values were recorded during 1998-2000 in several stream branches in the southern areas of the Inland Bays watershed including Blackwater Creek, Collins Creek, Dirickson Creek, Miller Creek, and Vines Creek. It is very unlikely that these extreme values are representative of typical condition in the Inland Bays. Chlorophyll *a* spikes of these magnitudes have been anecdotally reported in localized areas, but do not spatially represent the entire stream branch. Though the model may allow chlorophyll *a* to increase to such large levels, the input values are used to fence in the modeled values, and are used more as a representation of typical conditions than as a moment in time for a localized hot spot. Though the water quality database has exceptional spatial coverage considering the size of this model domain, stream branches often have but one sampling location representing it, influencing the entire network. Therefore, inclusion of these selected few extremes would skew the results for the rest of the area, and not be reflective of actual conditions. Therefore, for these watersheds, the input databases were filtered to replace any chlorophyll *a* concentration greater than 300 µg/L with 300 µg/L.

Like chlorophyll *a*, the 1998-2000 database contains a few instances of unusually low DO values. These extreme values are suspect of being the result of an unusual moment in time within the diurnal swing. Although the water quality model produces estimates of the daily diurnal swings, and has been shown to generate very low values in the daily cycle, the DO input database is used more as a representation of daily average conditions than an instantaneous moment in time. Applying these few outlier extreme DO measurements to the day's cycle produced aberrant results. Therefore, for the streams identified in the initial calibration with summertime average DO values less than the 5.5 mg/L criteria, the Bundicks Branch was used as a surrogate stream branch intended to represent typical stream DO conditions.

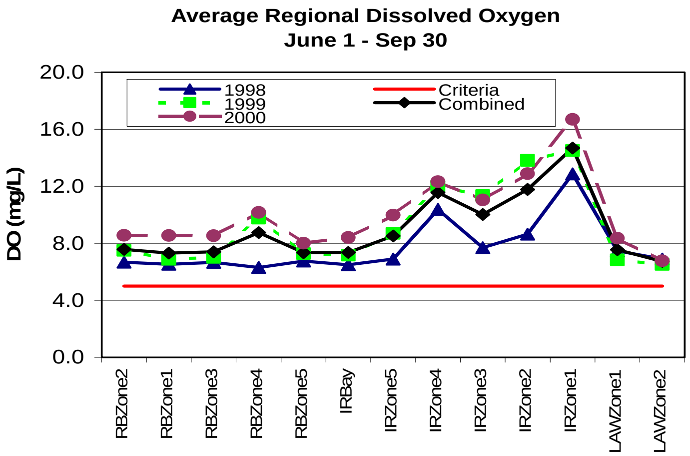
3.2 DERIVATION OF THE CRITICAL (DESIGN) CONDITIONS

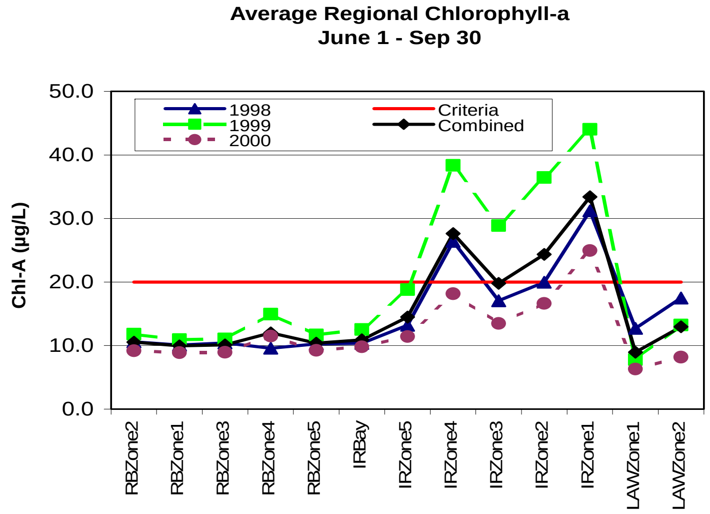
A critical condition is defined as a time when water quality parameters of concern simultaneously tend to assume more environmentally harmful values than other time periods for extended periods of time. Total Maximum Daily Loads must be established so that water quality standards are maintained even during these critical (design) conditions.

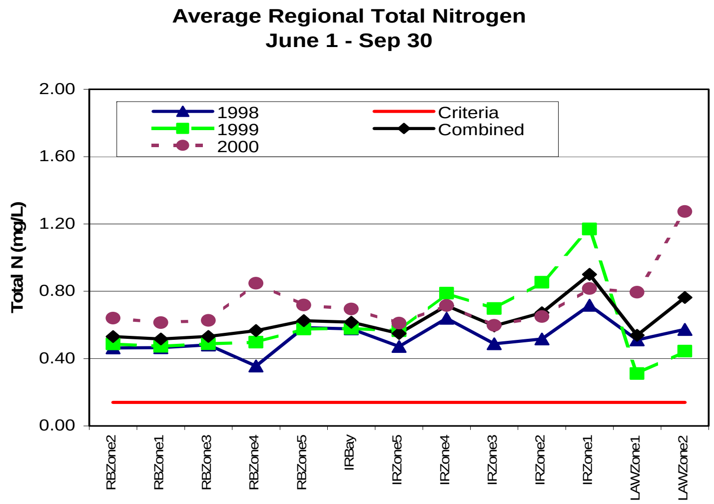
To identify the critical condition for the Inland Bays, the three years that formed the foundation of the GEMSS Inland Bays Model (1998, 1999, and 2000) were examined to determine which year, if any, provided the critical year. With conditions left "as is" before TMDL load reductions were applied, the model was run for each of these years. Since summer time is generally a critical time period, minimums, maximums, and averages at each river, bay, and major stream branch were examined for June 1 - September 30. The results of the analysis (Figure 3-1) upon the tidal regions (Figure 3-2) showed that there was no single year that was clearly the "worst year." The DO values were lowest in 1998. For nitrogen, 2000 was the critical year resulting in highest concentrations. For phosphorus, 2000 experienced the highest values of all the years in the upper Indian River, but 1998 had the highest values overall throughout all the regions. The highest chlorophyll *a* values were seen in 1999.

Lacking a single critical year, it was decided to use the averages over the three summers as the critical (design) condition for the TMDL analysis.

Figure 3-1. Critical Year Analysis Water Quality Comparisons







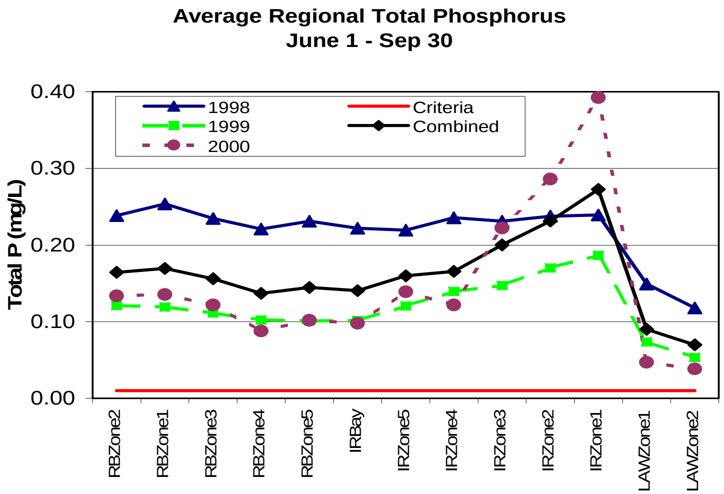


Figure 3-2. TMDL Analysis Regions – 3-D Model Zones

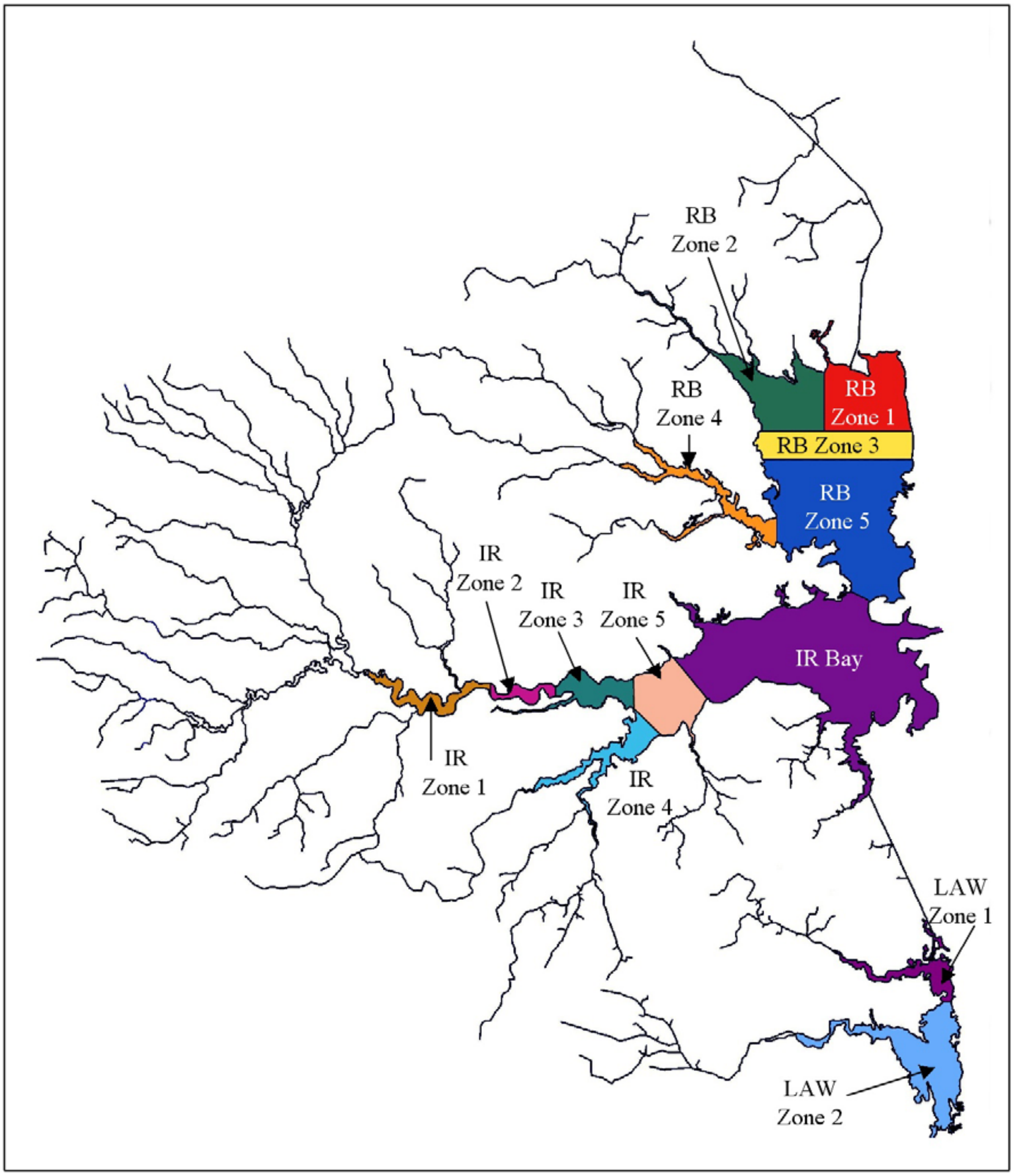
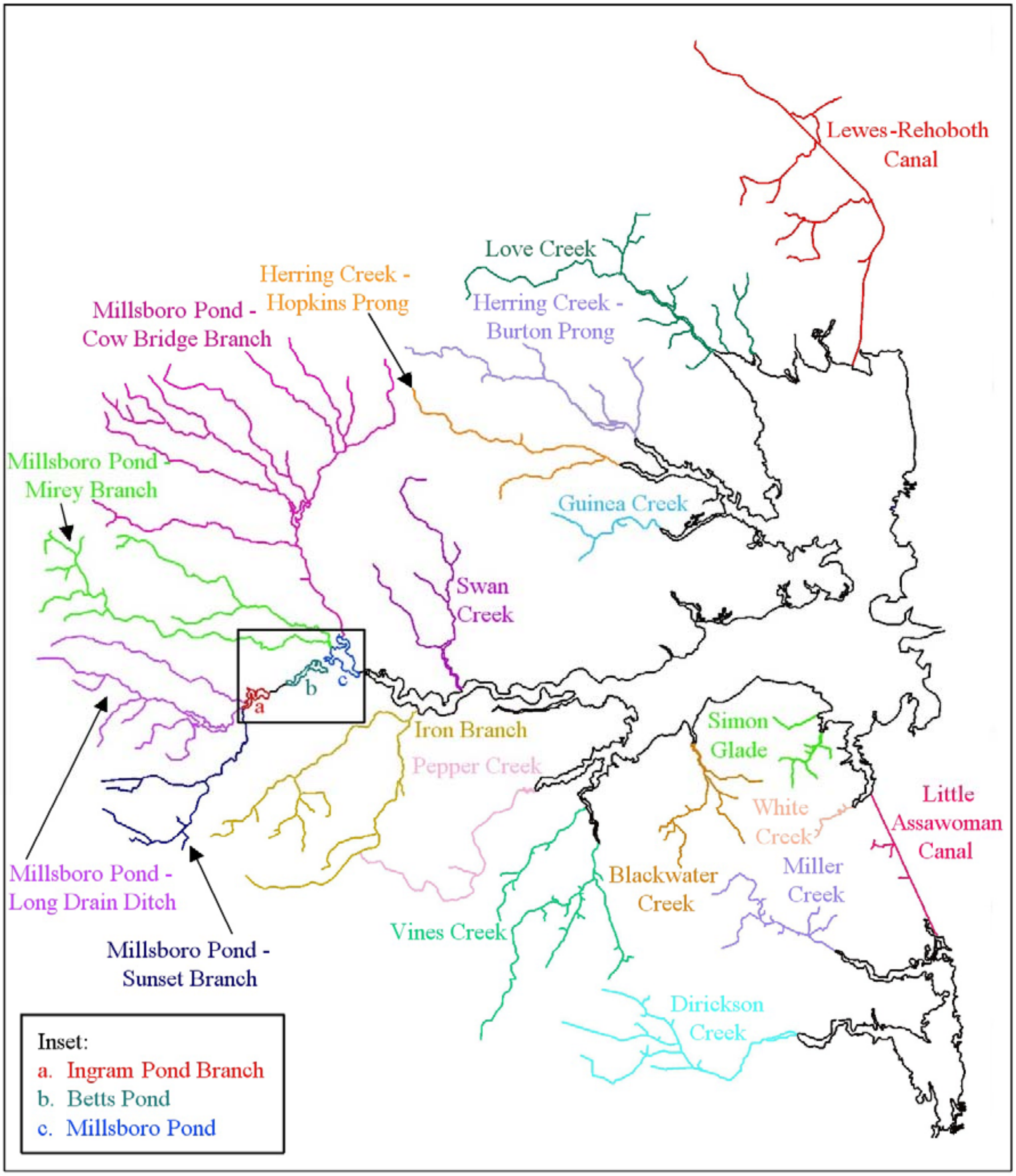


Figure 3-3. TMDL Analysis Regions – 1-D Model Zones



3.3 CURRENT CONDITIONS – THE BASE CASE

The calibrated GEMSS model was used as the foundation of the TMDL analysis. This Base Case is representative of current conditions, since there have been no significant changes to the Inland Bays since the 1998-2000 time period upon which the model was built. Load reductions were applied to the Base Case to estimate future conditions after TMDL implementation.

For analysis of the tidal areas of the Inland Bays were divided into regions (Figure 3-2), and three-year summertime average water quality conditions were taken. For the free flowing streams, 1-D stream contouring is used to display the three-year summertime average water quality conditions along the main stems of the streams (Figure 3-3). A single summertime average value was used for each parameter within the ponds.

Summertime averages for specific regions and streams were calculated as follows. The minimum, maximum and average values within every 3-D grid cell were obtained from the three model years (1998, 1999, and 2000) pooled together over the period of June 1 - September 30. These minimum, maximum and average values for each TMDL river and bay region were then obtained by averaging the minimum, maximum and averages of each grid cells within each TMDL region. The average of these minimum, maximum, and average values were taken within each TMDL river and bay region to obtain the final value compared to water quality criteria. For streams and ponds, the minimum, maximum and average of each constituent for every segment of a stream were obtained from the combined 3-year summertime TMDL Scenario outputs. These 3-year summertime average values are shown for DO, nitrogen, phosphorus, and chlorophyll *a* in Figures 3-4 and 3-5.

Nitrogen and phosphorus load estimates were calculated for streams (Table 3-1) and point-sources (Table 3-2) based upon summertime and annual average flow rates and concentrations.

The GEMSS-Inland Bays model produced different nutrient load estimates than the CH3D/CE-QUAL-ICM models run for the 1998 TMDL Analysis (DNREC, 1998). The GEMSS model was based upon different years than the 1998 model (1988-1990), and included a much more comprehensive database of physical and chemical properties to construct the model, both in terms of spatial coverage and frequency of measurements. In the 1998 CH3D/CE-QUAL-ICM model, TMDLs were obtained by multiplying the stream flow and concentration at the most downstream station (the confluence of the tributaries into the bays). The new values in GEMSS are based on upon a water quality database that includes stations along the entire stream network, and therefore results in more accurate modeling. A comparison of load estimates between the two models is found in Table 3-3.

Figure 3-4. Base Case - Summertime Averages for Rivers and Bays

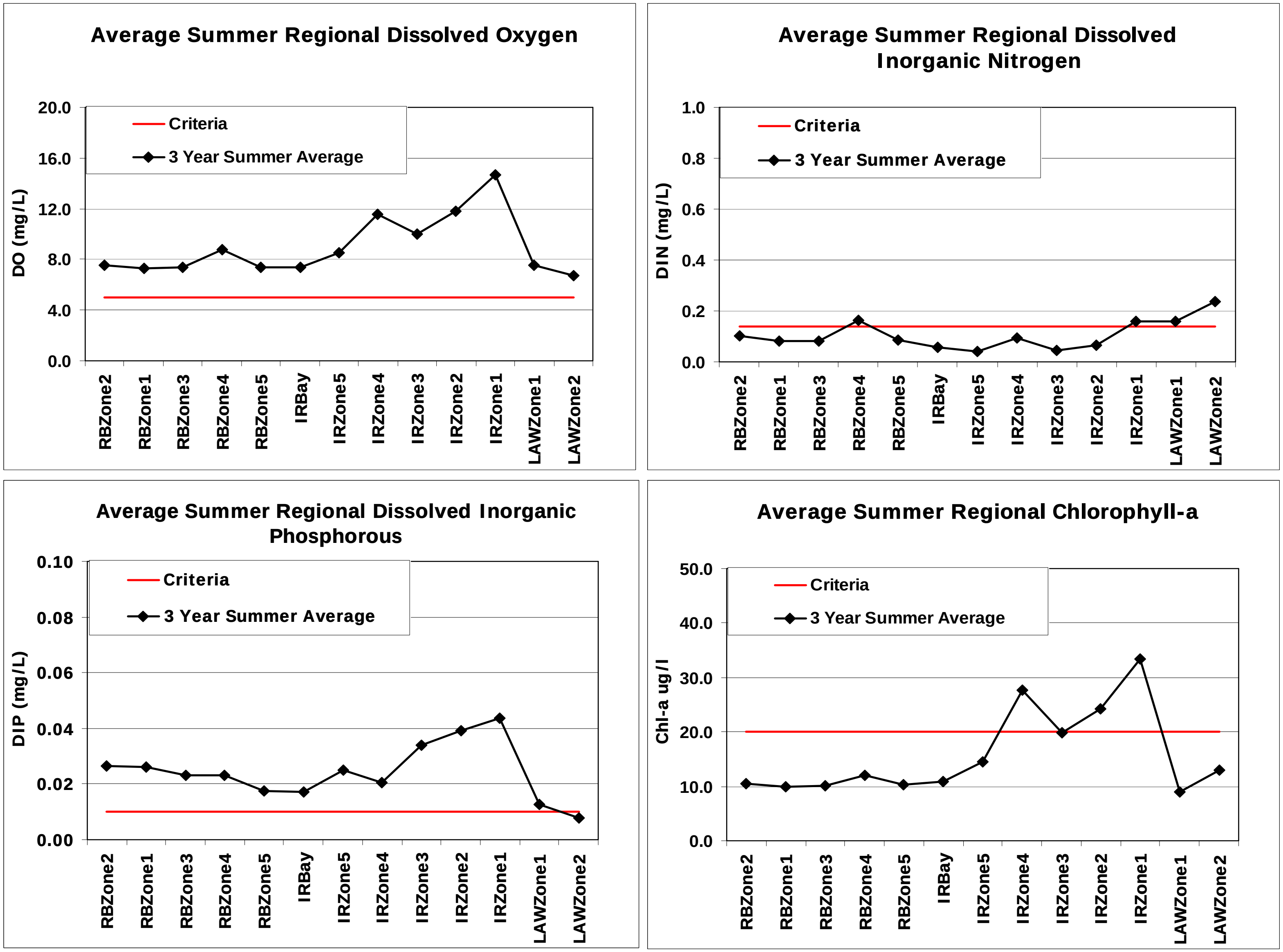


Figure 3-5. Base Case - Summertime Averages for Streams

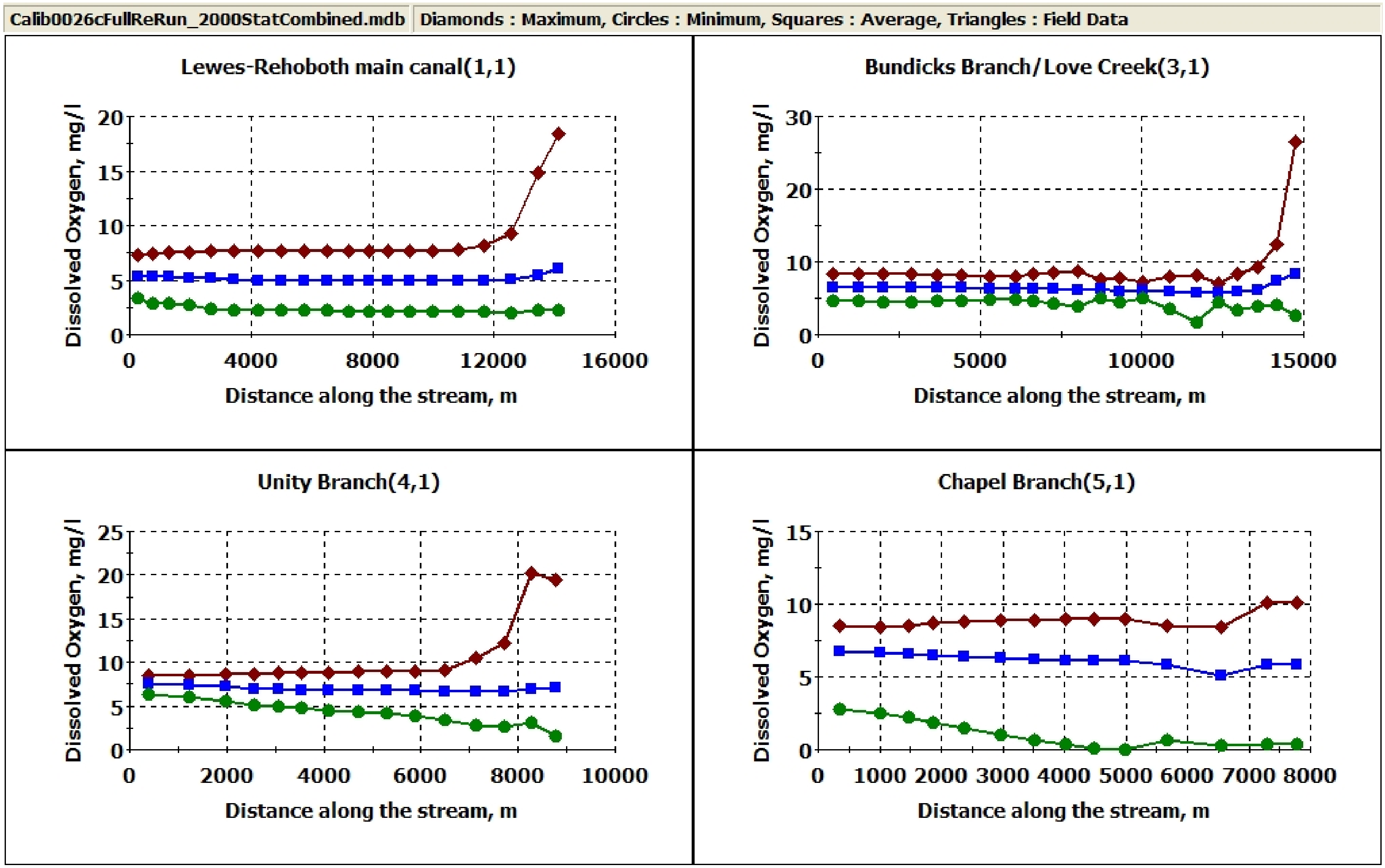


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

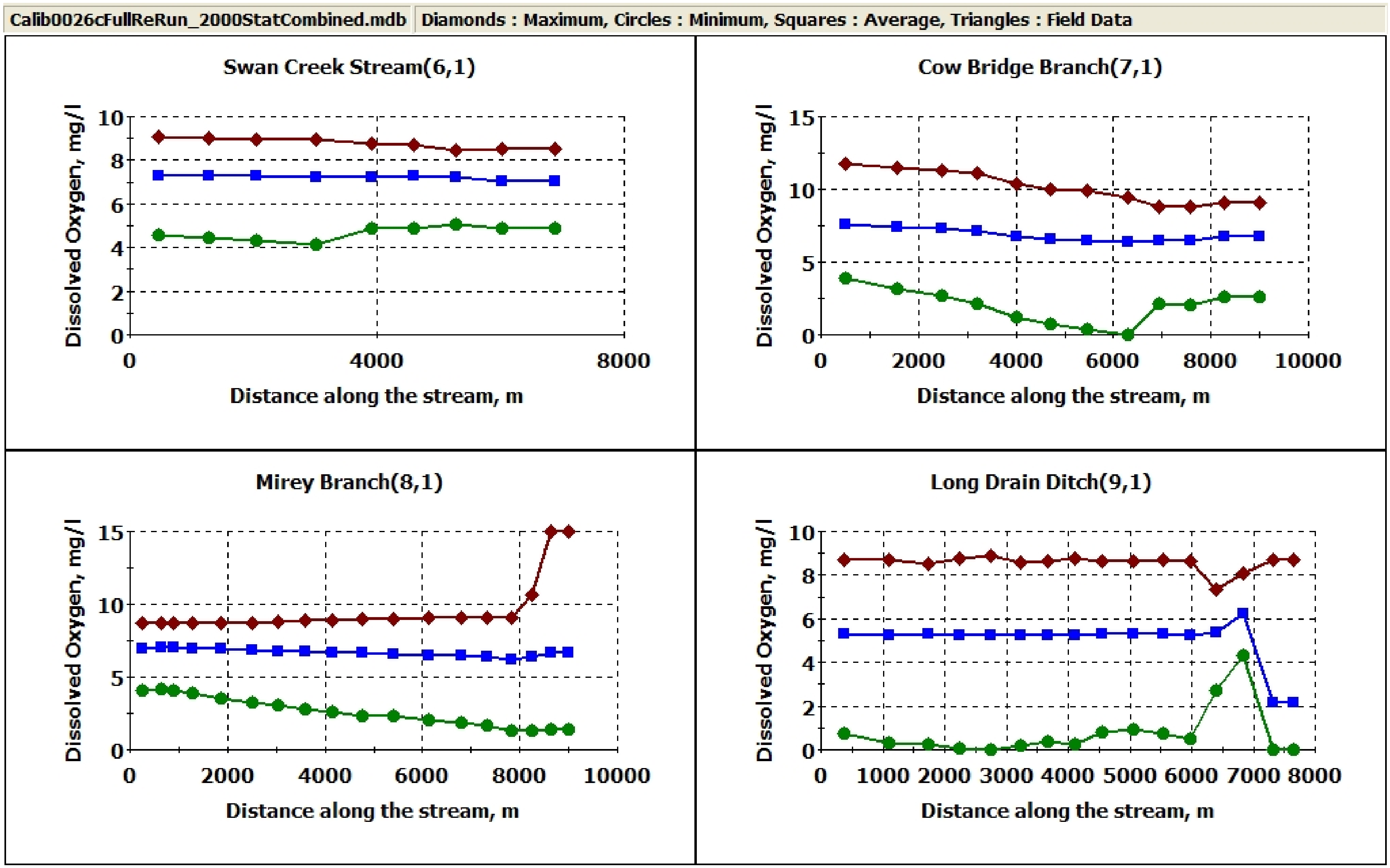


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

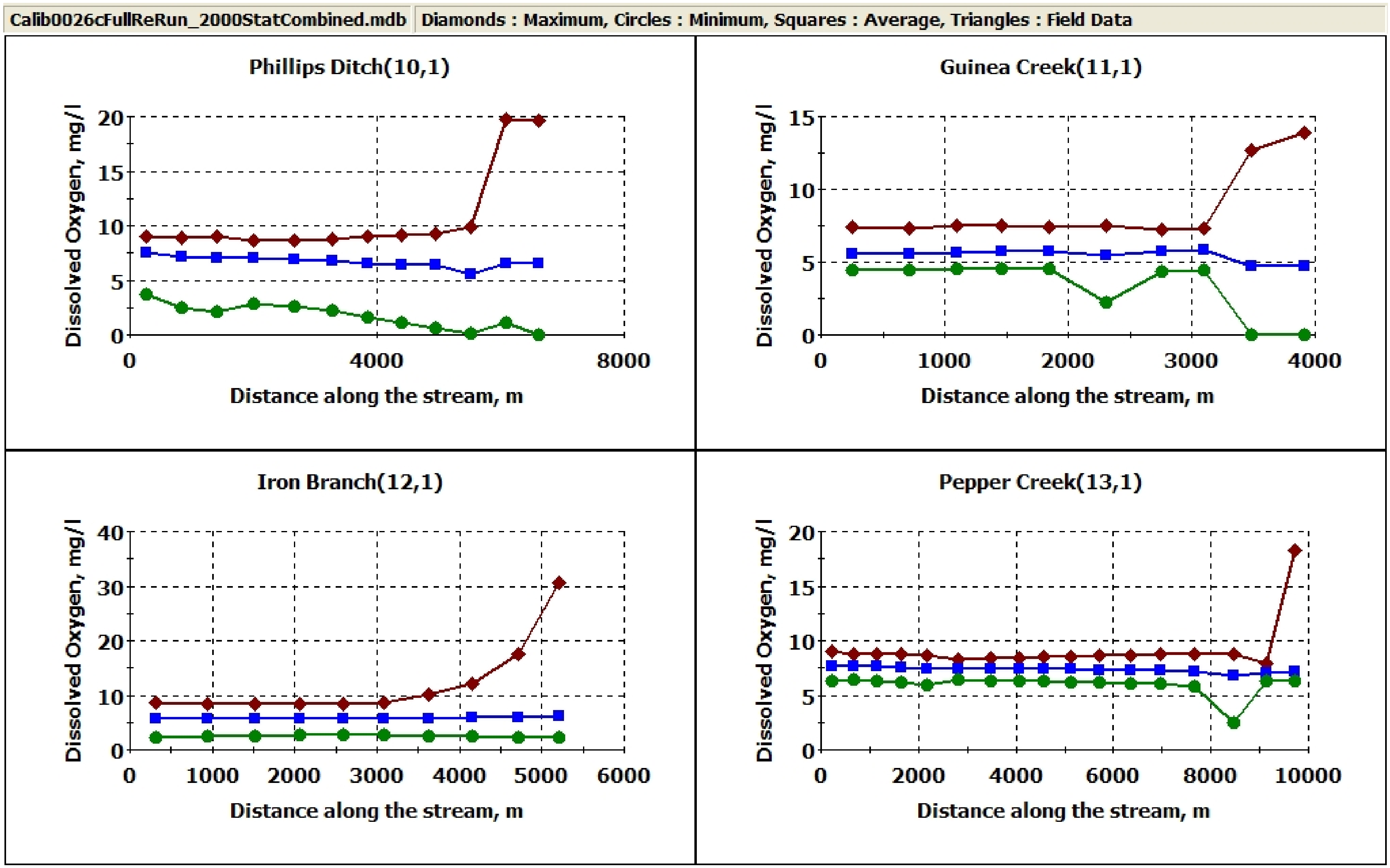


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

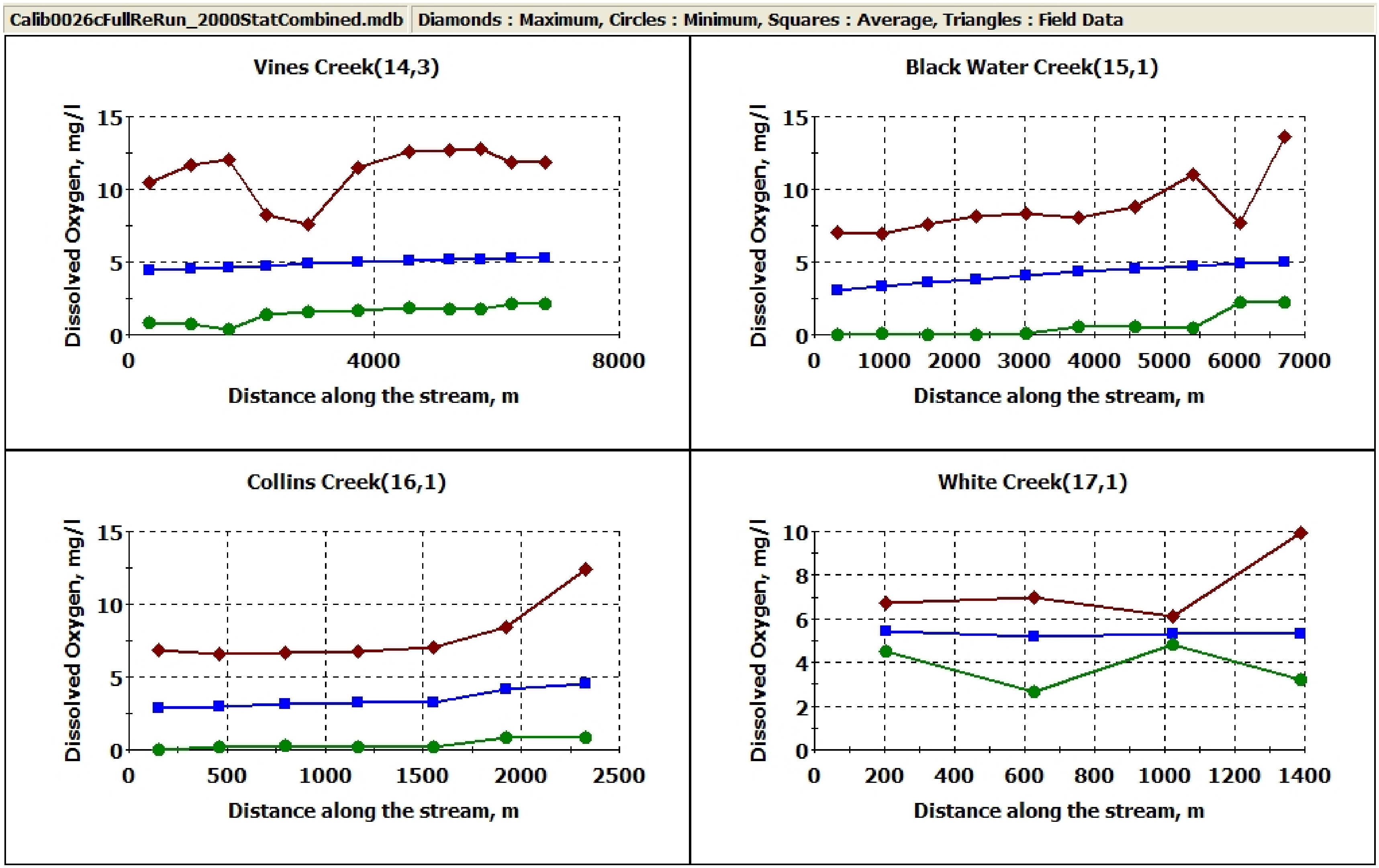


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

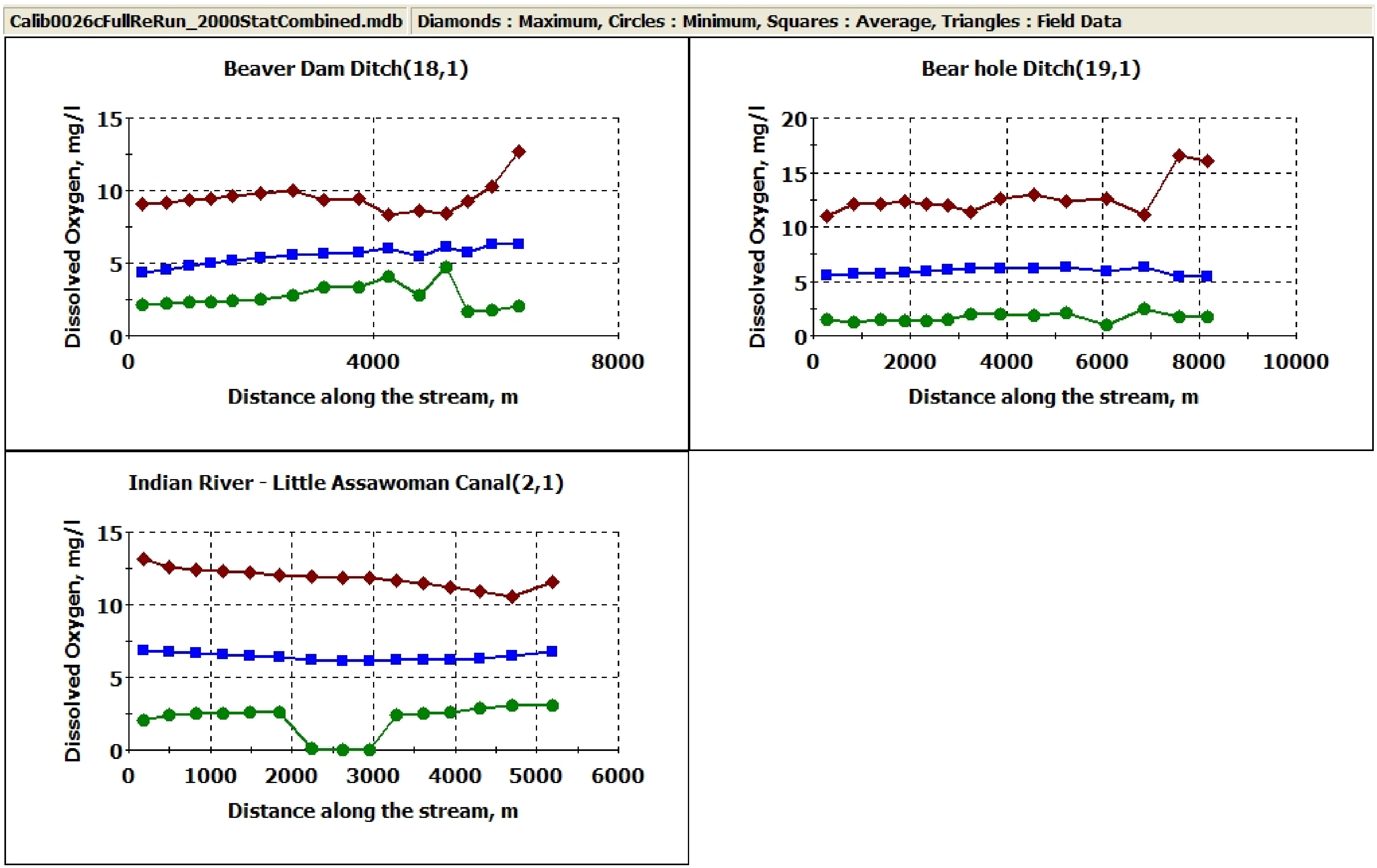


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

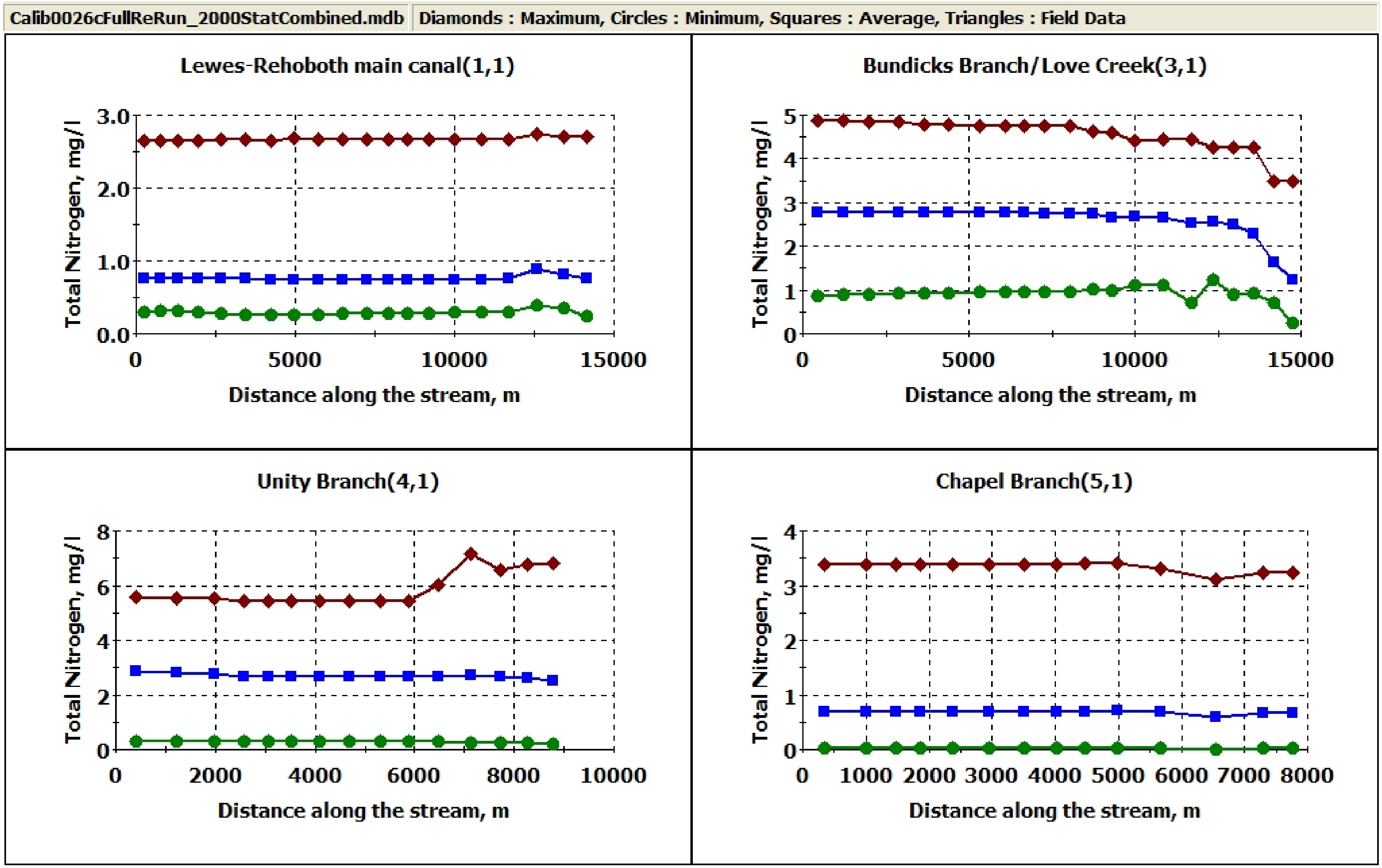


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

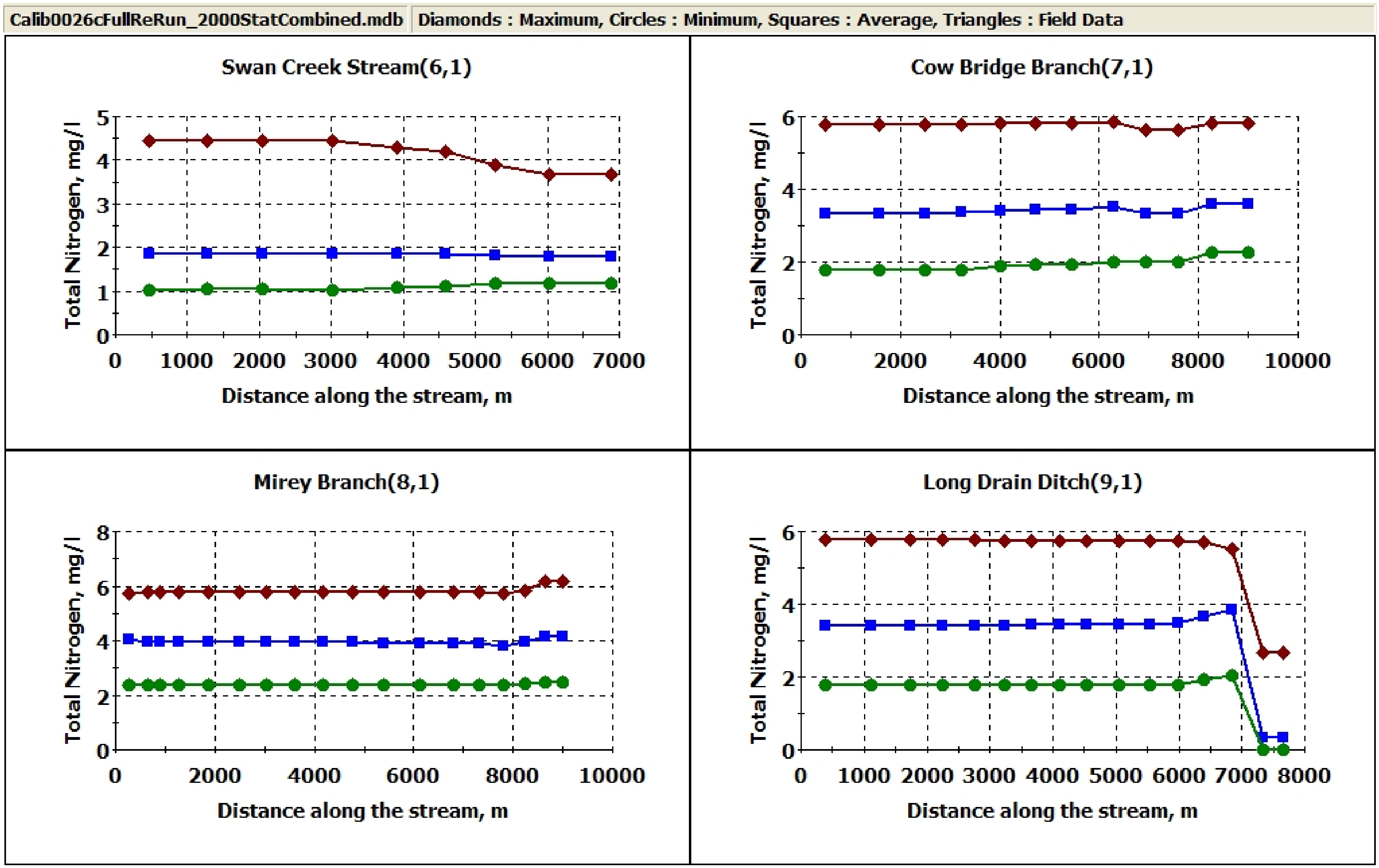


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

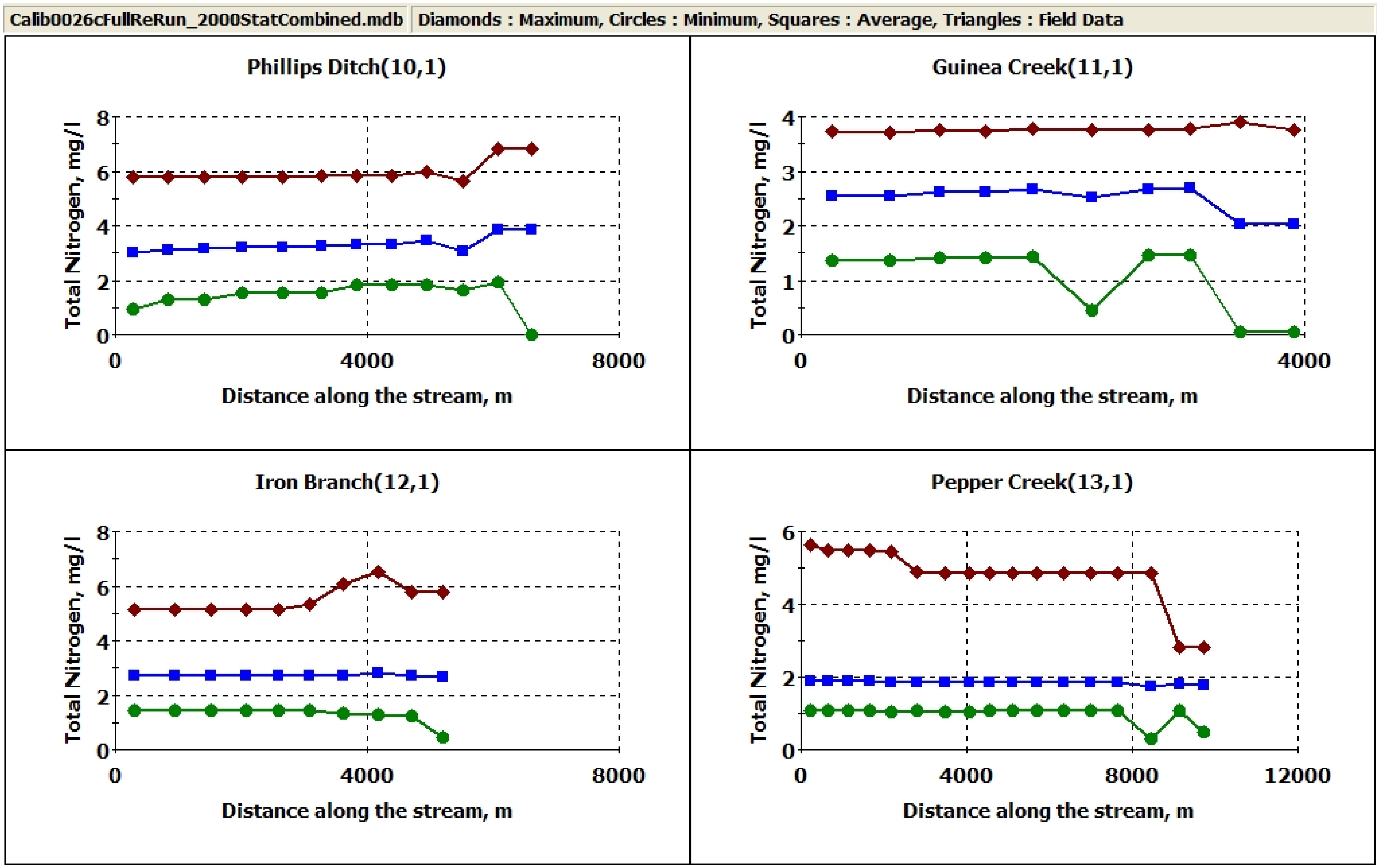


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

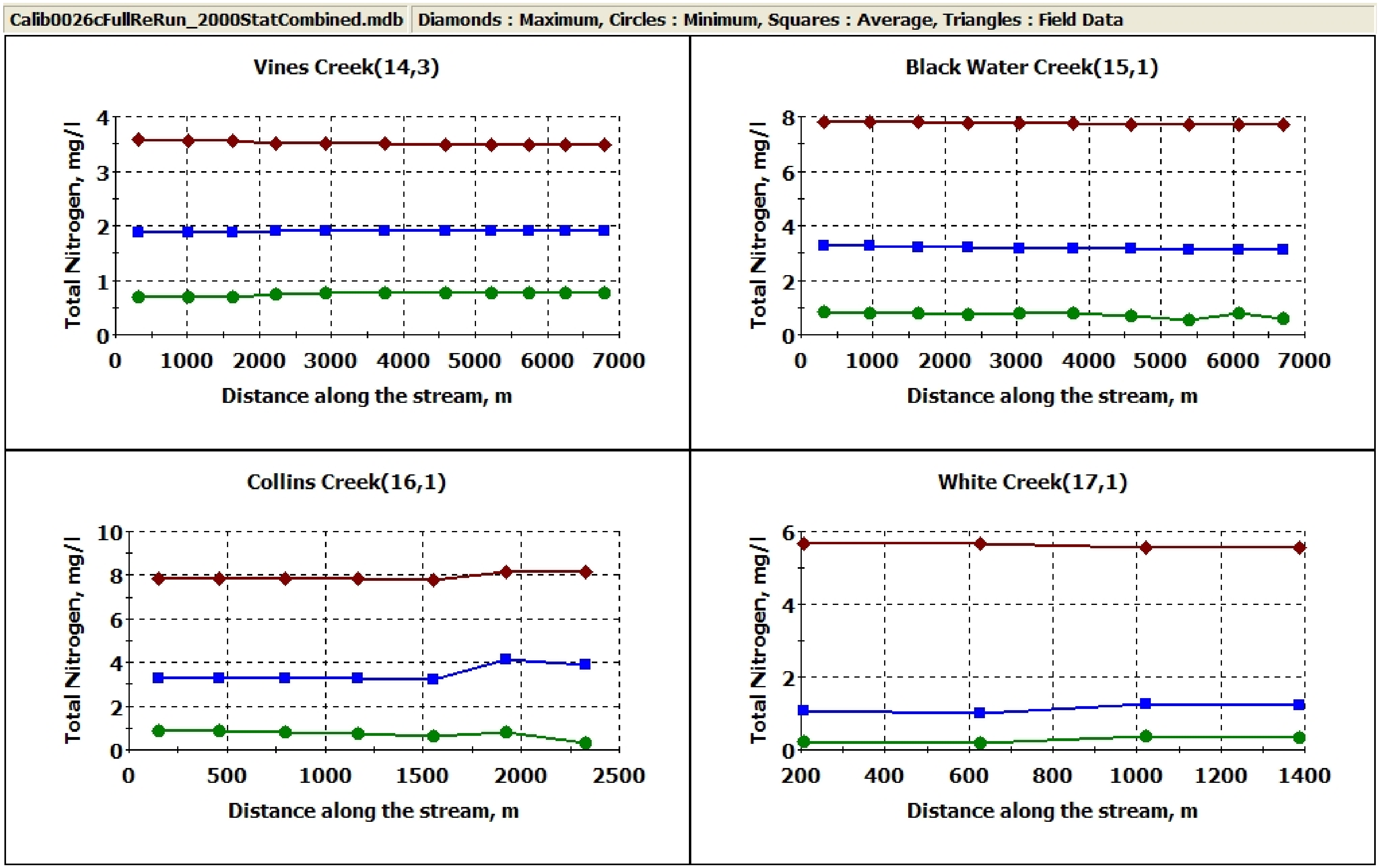


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

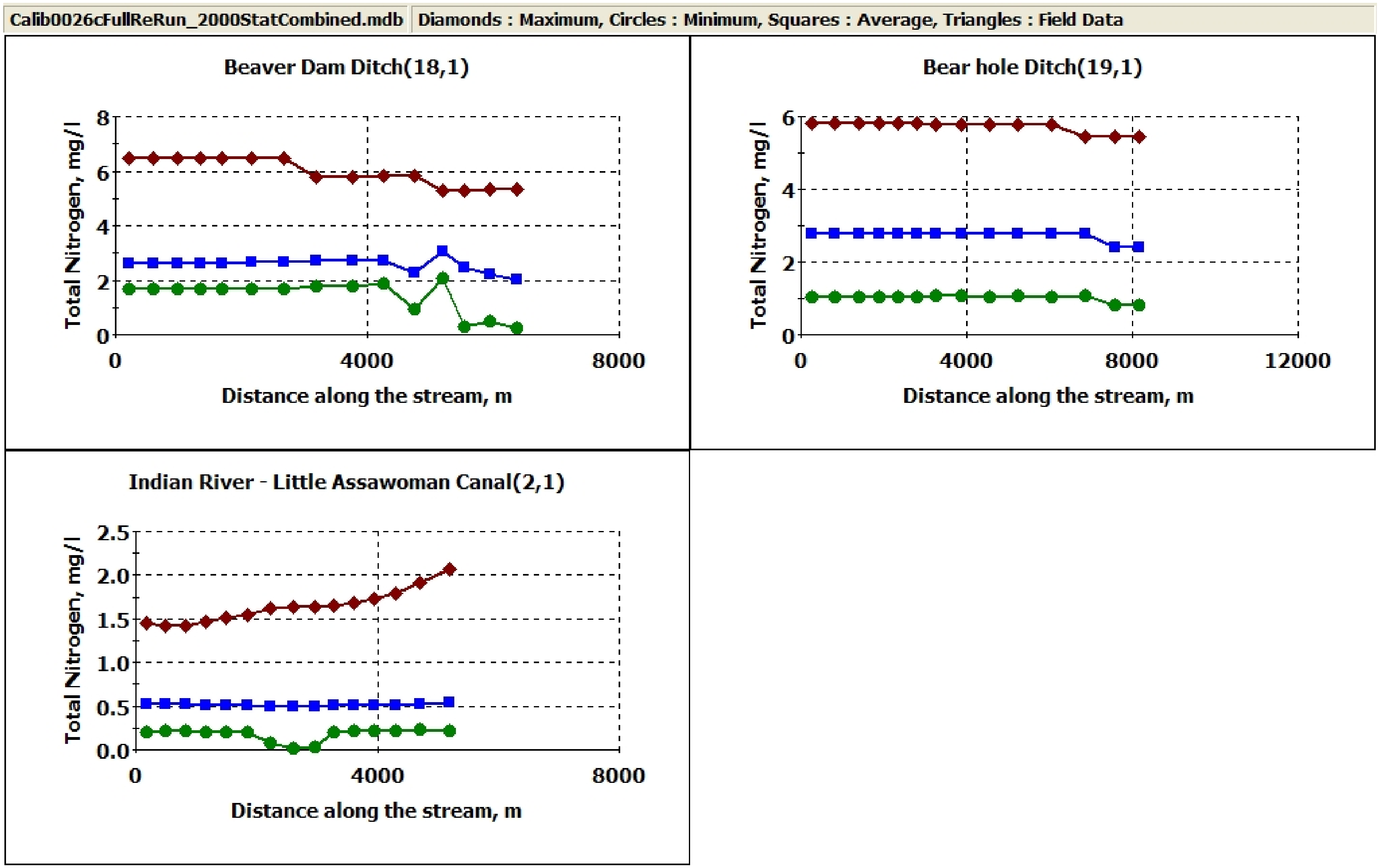


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

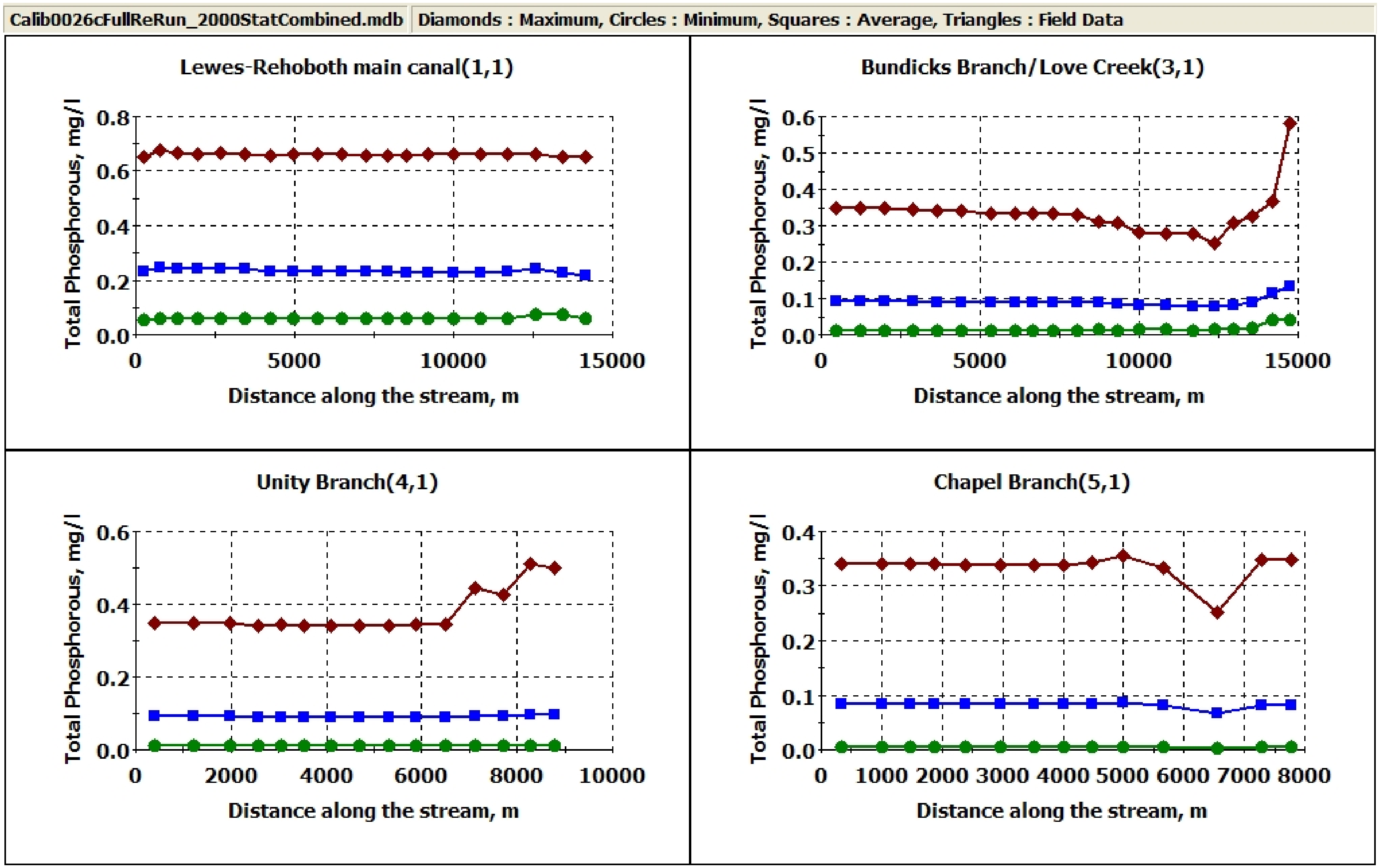


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

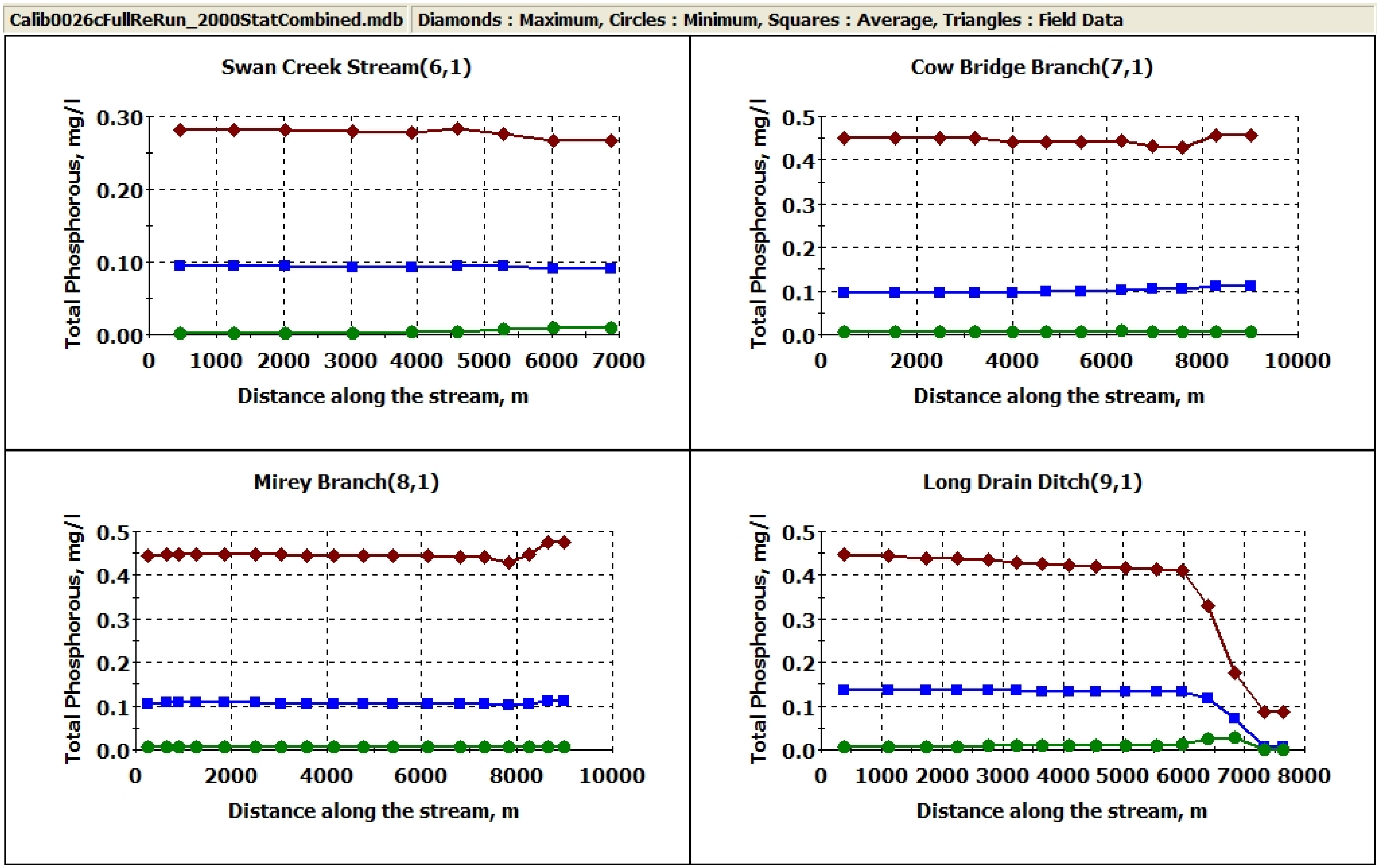


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

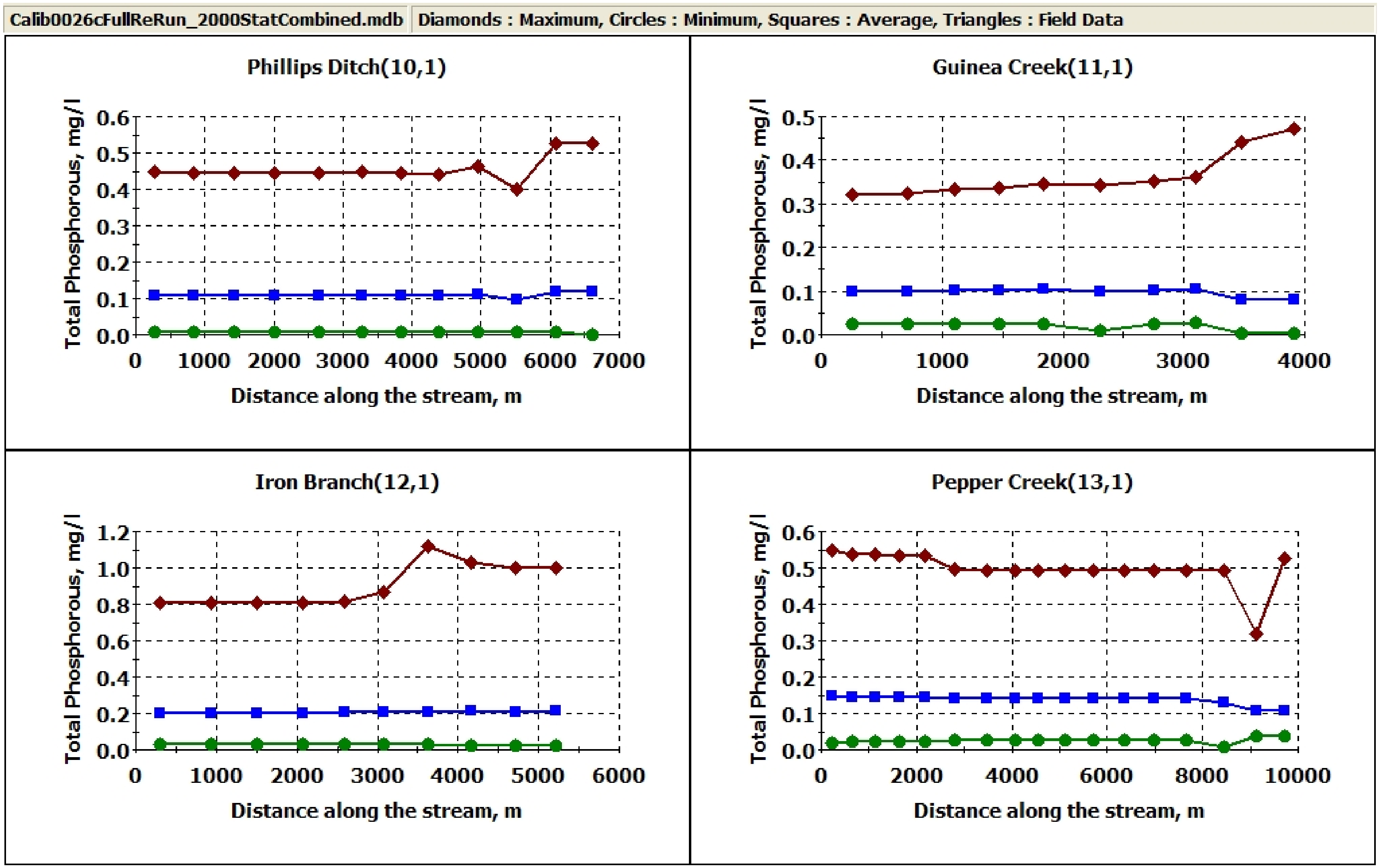


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

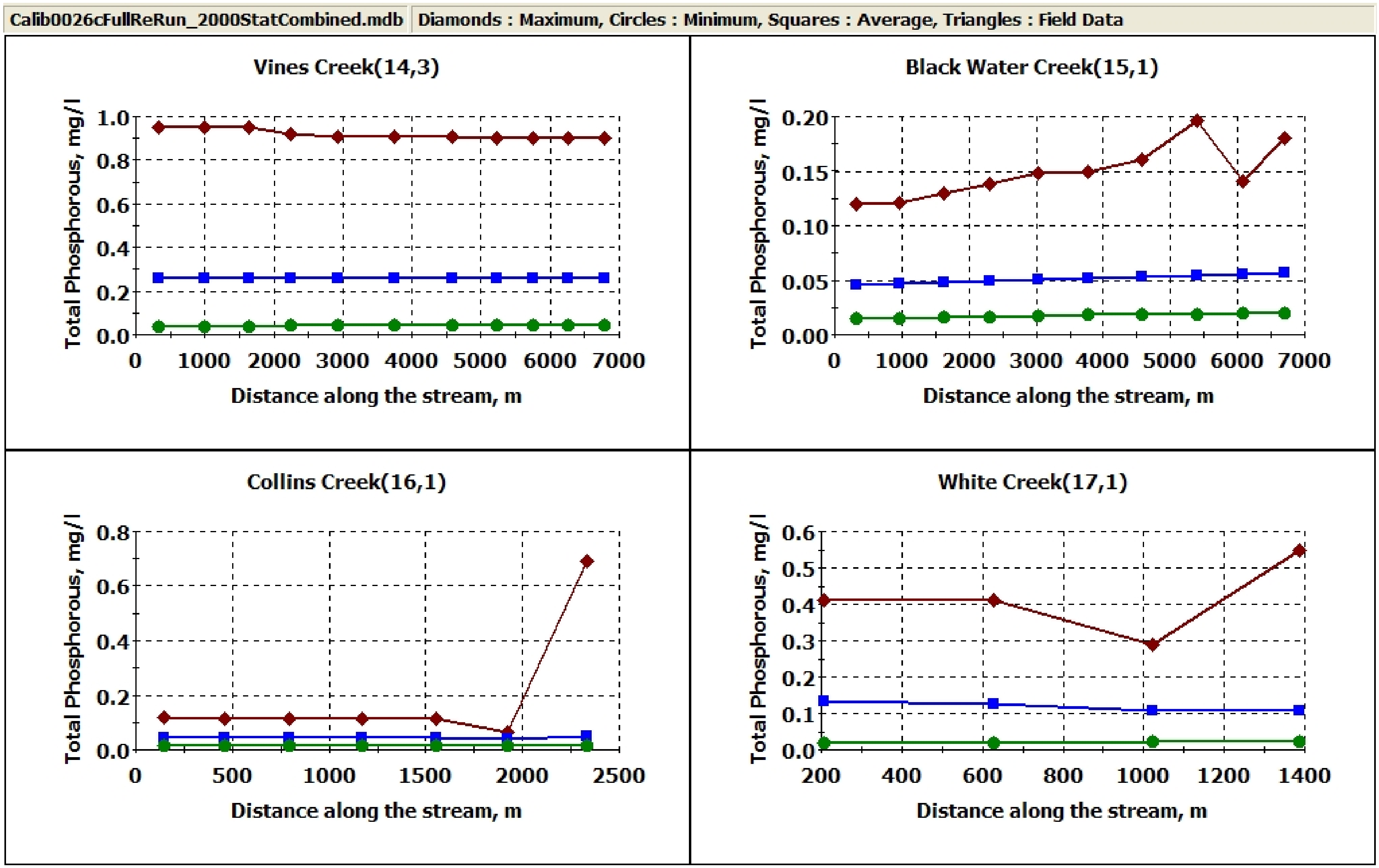


Figure 3-5. Base Case - Summertime Averages for Streams (continued)

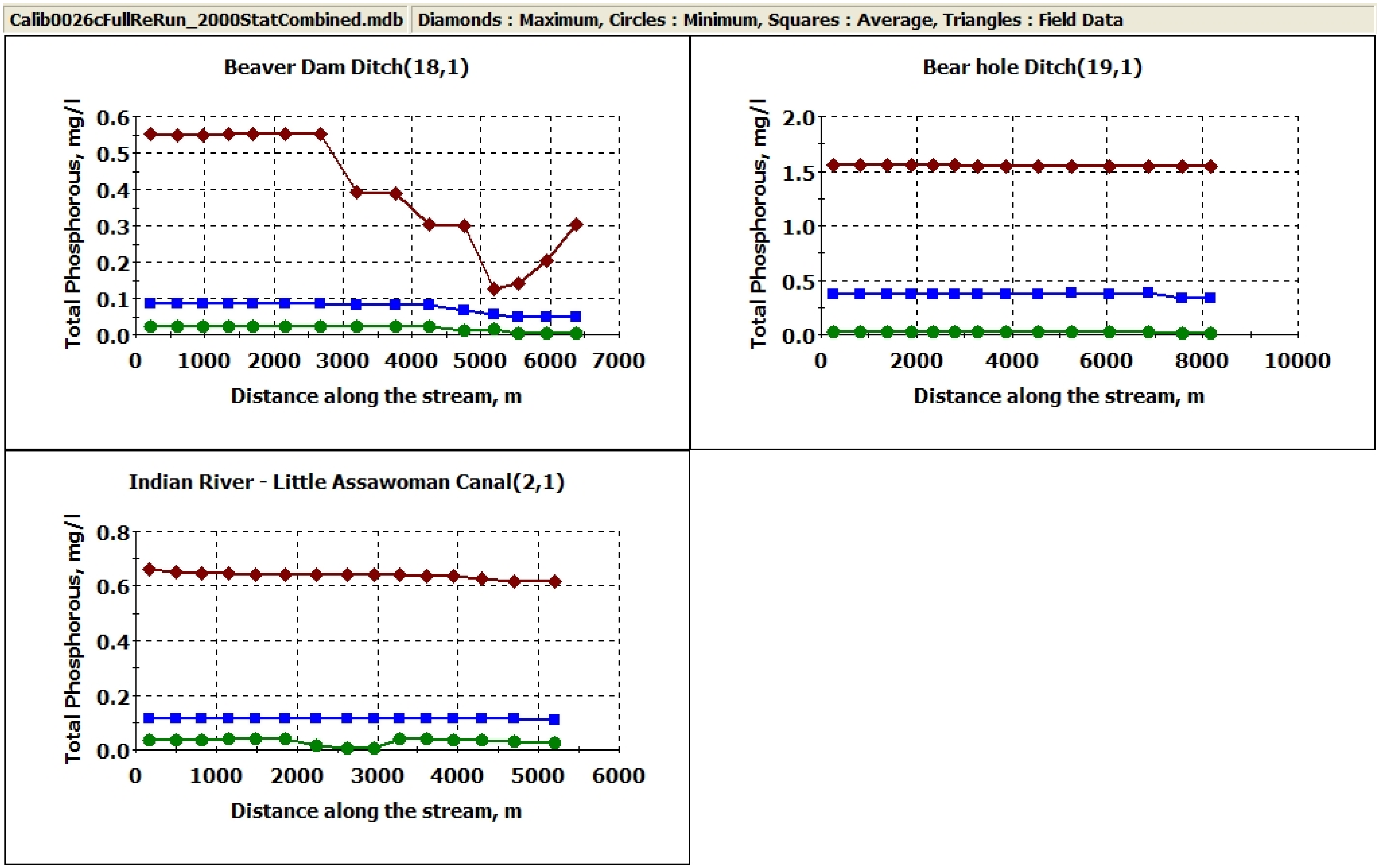


Table 3-1. Base Case Nonpoint Source Nitrogen and Phosphorus Loads

Base Case Receiving Body	Stream Branch	Total Nitrogen Annual Avg Load (kg/d)	Total Phosphorus Annual Avg Load (kg/d)
Rehoboth Bay	Lewes-Rehoboth Main Canal	55.1	8.8
	Love Creek	323.8	13.9
	Herring Creek-Hopkins Prong	85.7	3.3
	Herring Creek- Burton Prong	60.6	1.6
	Guinea Creek	175.9	8.4
Indian River and Bay	Swan Creek	198.2	4.1
	Millsboro Pond/Cow Bridge	477.5	5.1
	Millsboro Pond/Mirey Branch	230.8	2.3
	Millsboro Pond/Long Drain Ditch	192.7	2.0
	Millsboro Pond/SunSet Branch	238.9	1.7
	Iron Creek	437.2	5.9
	Pepper Creek	215.5	4.3
	Vines Creek	203.9	10.9
	Blackwater Creek	290.8	1.9
	White Creek	204.5	1.3
	Collins Creek	79.8	2.5
Little Assawoman Bay	Miller Creek	109.0	1.6
	Dirickson Creek	160.6	20.8
TOTAL		**3740.4**	**100.3**

Table 3-2. Base Case Point Source Nitrogen and Phosphorus Loads

Base Case Point Source Name	Total Nitrogen Annual Avg Load (kg/d)	Total Phosphorus Annual Avg Load (kg/d)
Georgetown STP	16.3	0.8
Rehoboth Beach STP	109.2	9.1
Lewes STP	34.0	7.2
Vlassic Foods, Inc.	2.8	0.8
Colonial Estates	1.3	0.1
Townsend Inc.	85.3	25.2
Bayshore Mobile Home Park	0.1	0.0
Millsboro STP	32.3	1.1
Total	**281.3**	**44.2**

Table 3-3. Comparison of Nitrogen and Phosphorus Loads between GEMSS and 1998 TMDL Modeling Base Cases

Base Case Receiving Body	Stream Branch	GEMSS TN (kg/d)	1998 TMDL TN (kg/d)	GEMSS TP (kg/d)	1998 TMDL TP (kg/d)
Rehoboth Bay	Lewes-Rehoboth Main Canal	55	96	8.8	5.2
	Love Creek	324	155	13.9	8.3
	Herring Creek-Hopkins and Burton	146	177	4.9	9.5
	Guinea Creek	176	88	8.4	4.8
Indian River	Lingo Creek	-	39	-	2.1
	Swan Creek	198	155	4.1	8.4
	Millsboro Pond	1140	717	11.1	11.9
	Iron Creek	437	170	5.9	9.2
	Pepper Creek	215	113	4.3	6.1
	Vines Creek	204	109	10.9	5.8
	Blackwater Creek	291	94	1.9	5.0
	Collins Creek	205	-	1.3	-
	White Creek	80	89	2.5	4.8
Little Assawoman Bay	Miller Creek	109	-	1.6	-
	Dirickson Creek	161	-	20.8	-
	TOTAL	**3740**	**2002**	**100.3**	**81.1**

3.4 TMDL Analysis

3.4.1 Analysis Overview

The TMDL analysis was comprised of validating the efficacy of the 1998 TMDL, as well as generating the TMDL for the areas in the Inland Bays not included in the 1998 TMDL including the tributaries of Little Assawoman Bay. Using the calibrated Base Case, load reductions were applied as described in Section 1.3. The TMDL Scenario was then run and compared to water quality criteria and target values.

Under the guidelines of the 1998 report, more stringent load reductions were assigned to the upper Inland Bays compared to the rest of the system. Nonpoint source load reductions upon all forms of nitrogen and phosphorus in the 1-D model stream and pond segments were applied. All point source nutrient loads were reduced to zero. Atmospheric deposition of nitrogen was reduced 20%.

Sediment nutrient load rates were reduced to reflect the natural response to load reductions in the overlying water column. The sediment nutrient flux reductions were applied to both the tidal and non-tidal sections of the model. Sediment nitrogen and phosphorus were reduced following the reduction scheme of the nonpoint source loads such that 60% reductions in N & P sediment fluxes were applied to the input stations in central and eastern Indian River, Rehoboth Bay, and Little Assawoman Bay. 85% N / 65% P reductions were applied to the sediment flux station in the upper Indian River by Millsboro (ENTRIX, 2004).

In addition, the sediment oxygen demand (SOD) flux was also reduced in order to reflect the positive effect nutrient reductions will have upon sediment sinks of DO. Using the nutrient TMDL reduction values for N and P as a basis, a 65% reduction of SOD was applied to the upper Indian River, while a 40% reduction of SOD was applied to all other areas.

Ocean Boundary Phosphorus

Phosphorus in the near shore ocean water quality data was examined and determined to reflect an unrealistic input into the Inland Bays TMDL Scenario. The near shore ocean water quality is used in the model as a boundary condition. That is, the concentrations in the ocean are not modeled, but used only as inputs into the model at the edges of the model grid domain. The water quality measured in the ocean boundary during 1998 through 2000 showed high levels of DIP. These sampling locations in the ocean are influenced by the water quality that exits in the Inland Bays. Once the TMDL reductions are applied, the water at the ocean boundary should respond with lower concentrations as well. Since the currently elevated ocean DIP would be used incorrectly as a potent source of DIP into the Inland Bays, to reflect future conditions all ocean boundary DIP concentrations were filtered to restrict a maximum value of 0.01 mg/L.

Total Orthophosphate Conversion into DIP

The current version of the GEMSS-Inland Bays model outputs values of orthophosphate in terms of its total form (dissolved plus particulate), not in its dissolved form alone. The water quality criteria within the tidal areas are based upon dissolved form of inorganic phosphorus (i.e. dissolved orthophosphate since other inorganic forms of phosphorus break down into orthophosphate in the aquatic environment). An adjustment factor was necessary to estimate DIP from the model's predicted values of total orthophosphate. Using nutrient measurements taken within the Inland Bays from the STORET database in 1993, and recently during special studies performed by DNREC on November 2001 and May 2002, an average ratio of dissolved to total orthophosphate was 38:100. This 38% factor was applied to estimate DIP from the model output of total orthophosphate.

3.4.2 Results of the TMDL Scenario

After application of the adjustments described above, the results of this Scenario demonstrated the effectiveness of the TMDL reductions upon point and nonpoint sources to achieve water quality goals throughout the Inland Bays. The results are found in Figures 3-6, 3-7, and 3-8. Table 3-4 and Table 3-5 show the TMDLs for nitrogen and phosphorus resulting from the prescribed point and nonpoint source reductions upon the main stream branches of the Inland Bays and reduction of atmospheric deposition. Since the 1998 TMDL yielded different estimates of loads as described in Section 3.3, new TMDL values have been generated. Despite the increased estimation of the nutrient loads in the tributaries, water quality standards are met using the 1998 TMDL recommendations.

Table 3-4. Proposed TMDLs for the Inland Bays Summary

Source	Base Case (1998-2000)		TMDL Scenario (for a normal rainfall year)	
	Nitrogen Load (kg/d)	Phosphorus Load (kg/d)	Nitrogen Load (kg/d)	Phosphorus Load (kg/d)
Point Sources	281.3	44.2	0	0
Nonpoint Source	3740.4	100.3	1256.7	51.1
Atmospheric Nitrogen Deposition	765	N/A	612	N/A

Table 3-5. Inland Bays TMDLs for Nitrogen and Phosphorus Loads

TMDL Scenario Stream Branch	Total Nitrogen Annual Avg Load (kg/d)	Total Phosphorus Annual Avg Load (kg/d)
Lewes-Rehoboth Main Canal	33.0	5.3
Love Creek	194.3	8.3
Herring Creek-Hopkins Prong	51.4	2.0
Herring Creek- Burton Prong	36.4	1.0
Guinea Creek	105.5	5.0
Swan Creek	29.7	1.4
Millsboro Pond / Cow Bridge	71.6	1.8
Millsboro Pond / Mirey Branch	34.6	0.8
Millsboro Pond / Long Drain Ditch	28.9	0.7
Millsboro Pond / SunSet Branch	35.8	0.6
Iron Creek	65.6	2.1
Pepper Creek	32.3	1.5
Vines Creek	30.6	3.8
Blackwater Creek	174.5	1.1
White Creek	122.7	0.8
Collins Creek	47.9	1.5
Miller Creek	65.4	0.9
Dirickson Creek	96.4	12.5
TOTAL	**1256.7**	**51.1**

Figure 3-6. TMDL Scenario - Summertime Averages for Rivers and Bays

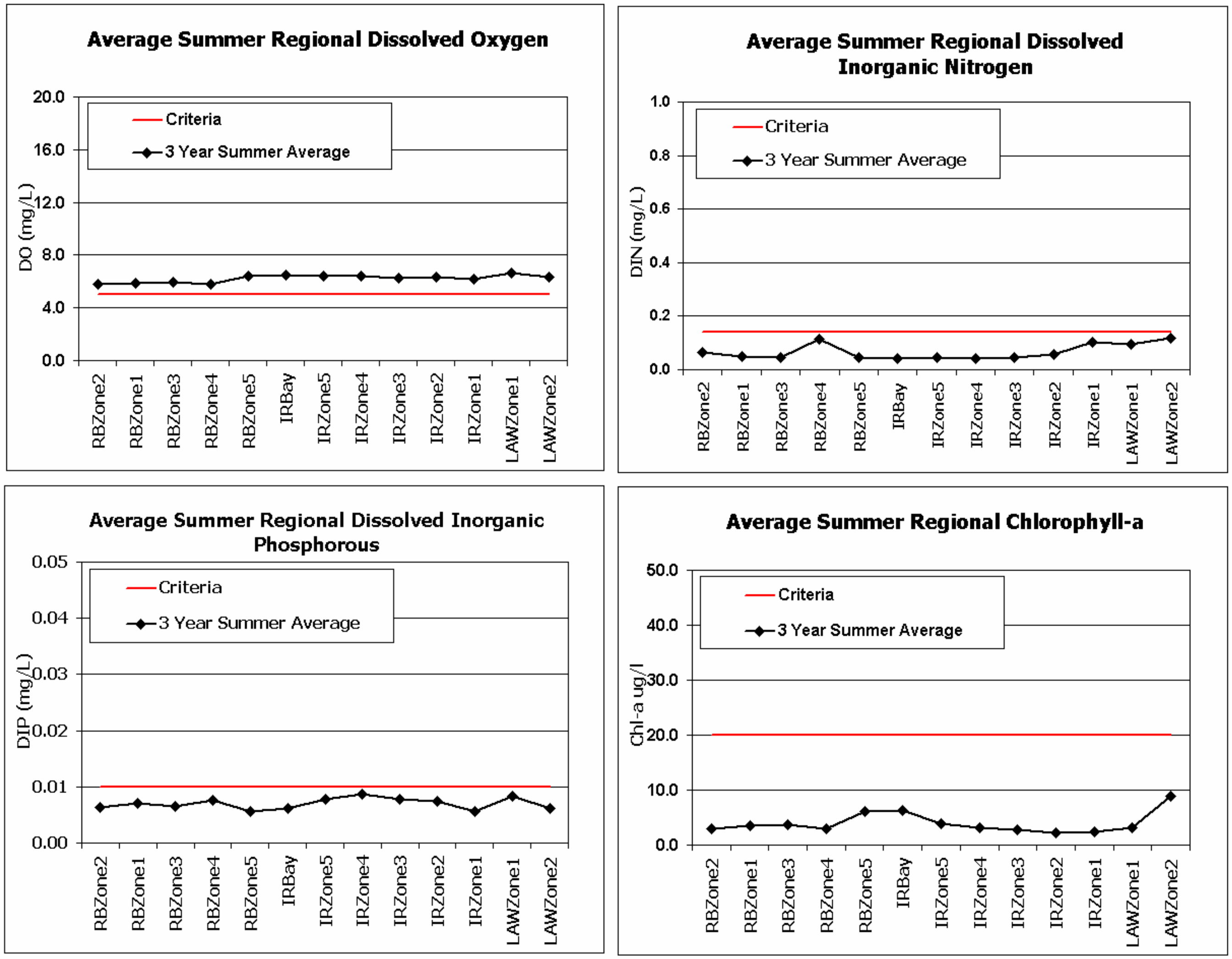


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams

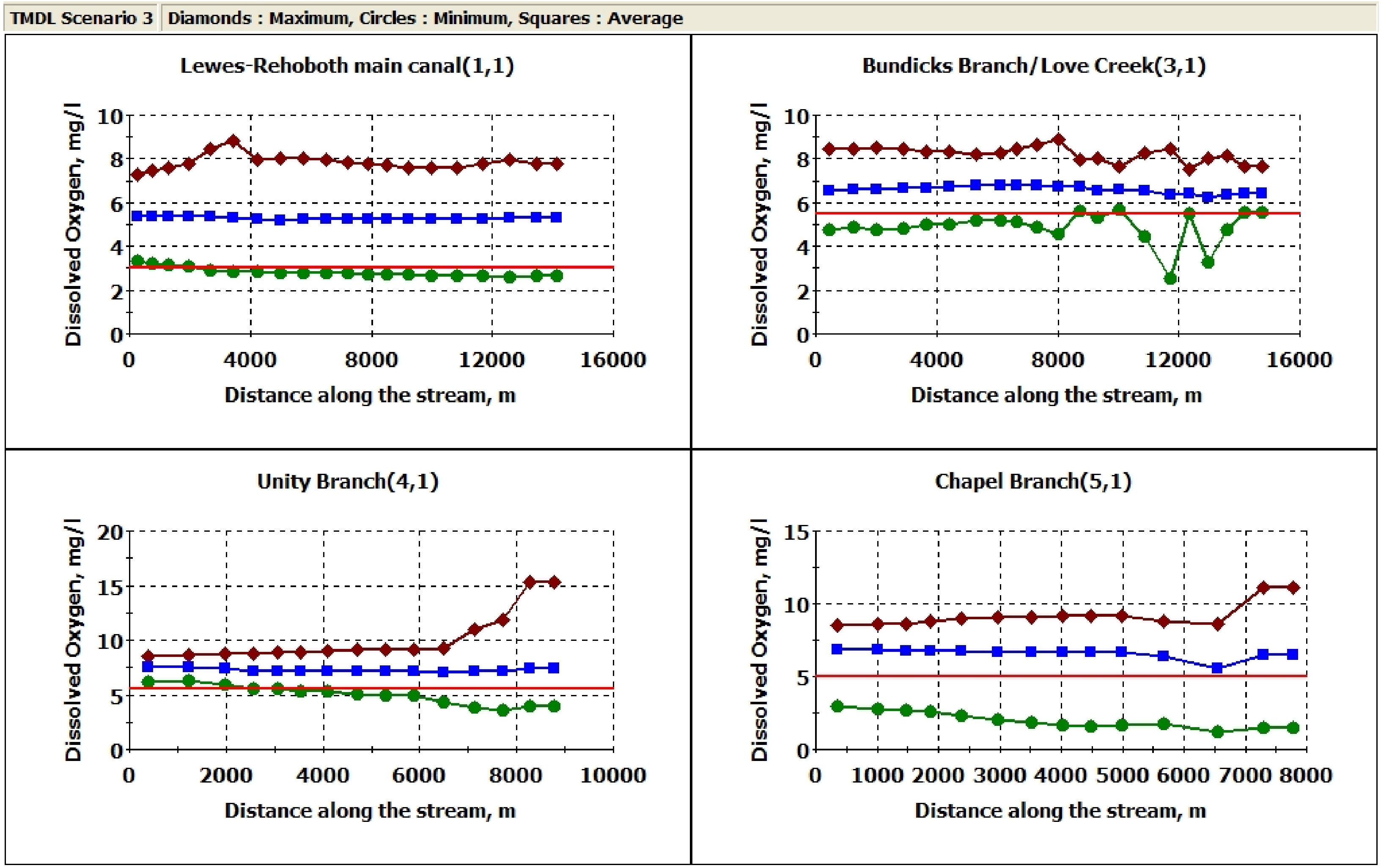


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

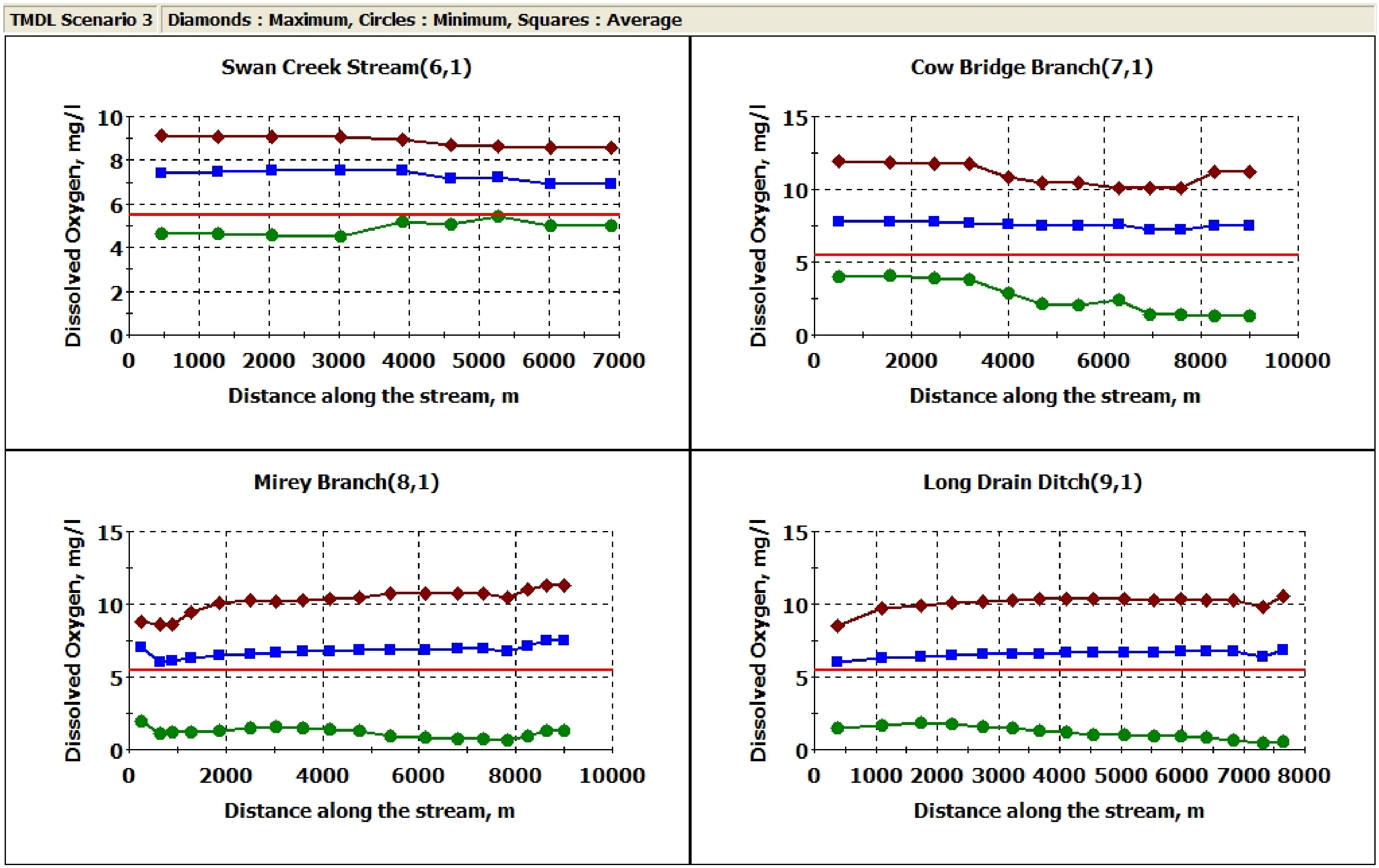


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

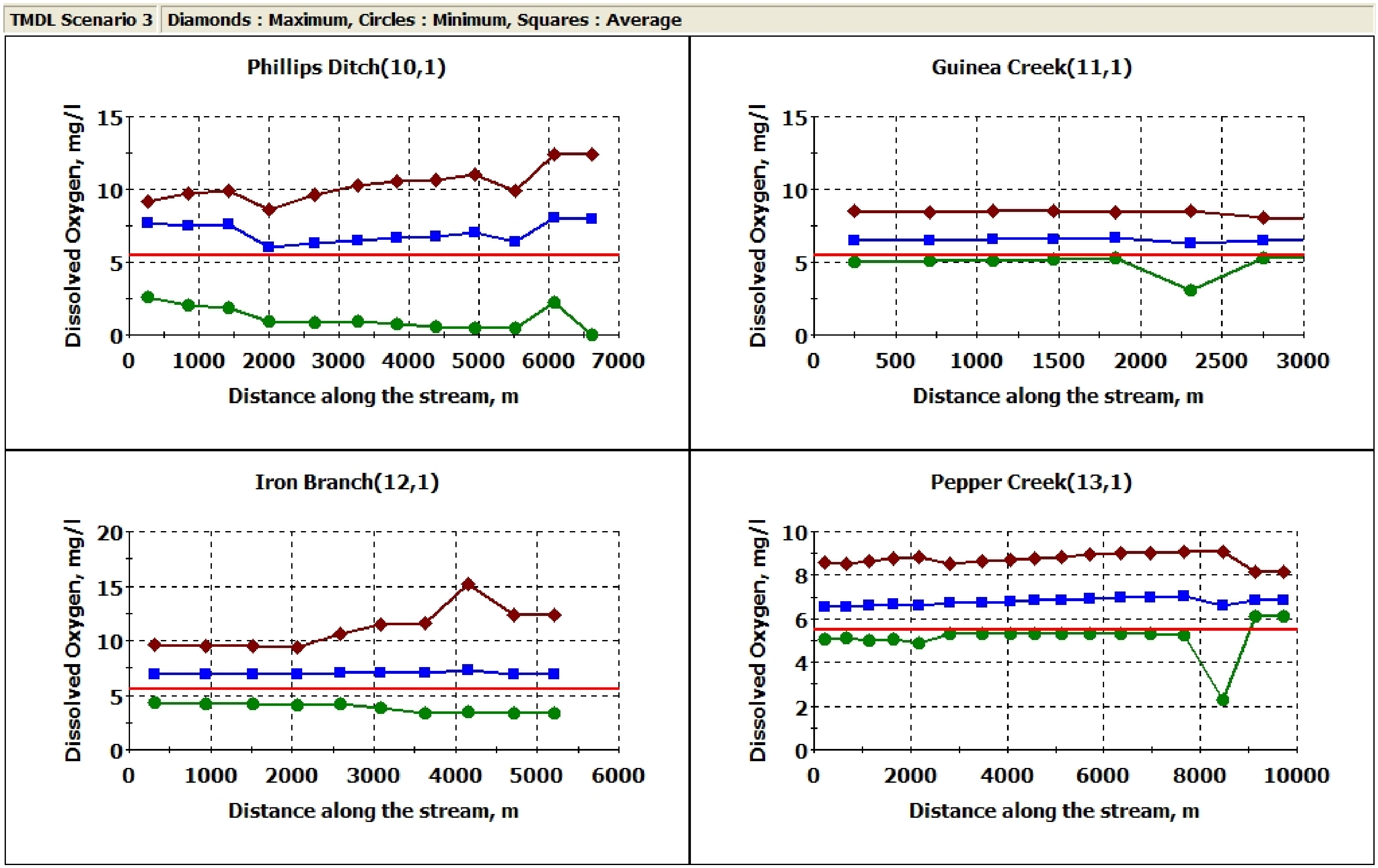


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

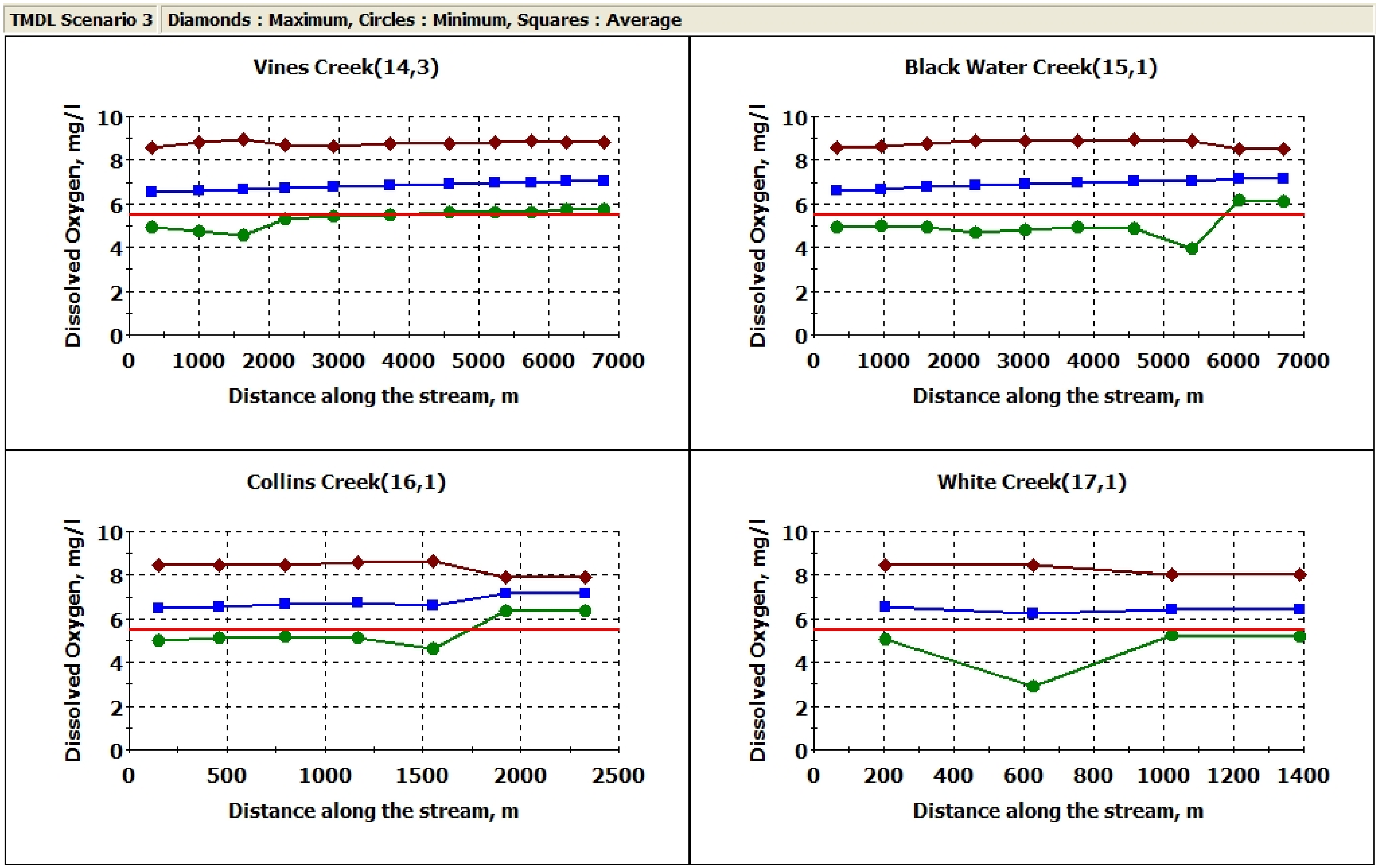


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

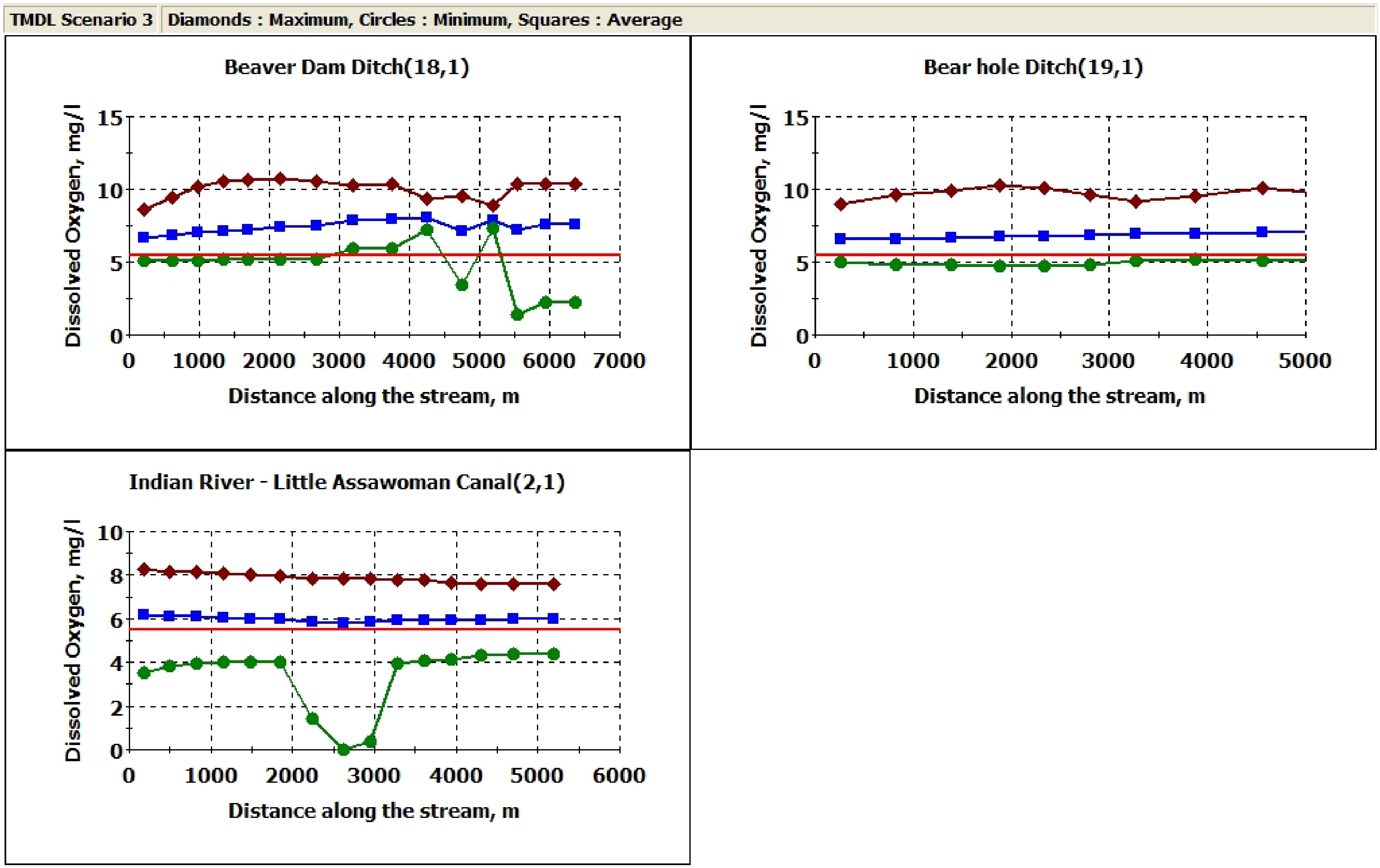


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

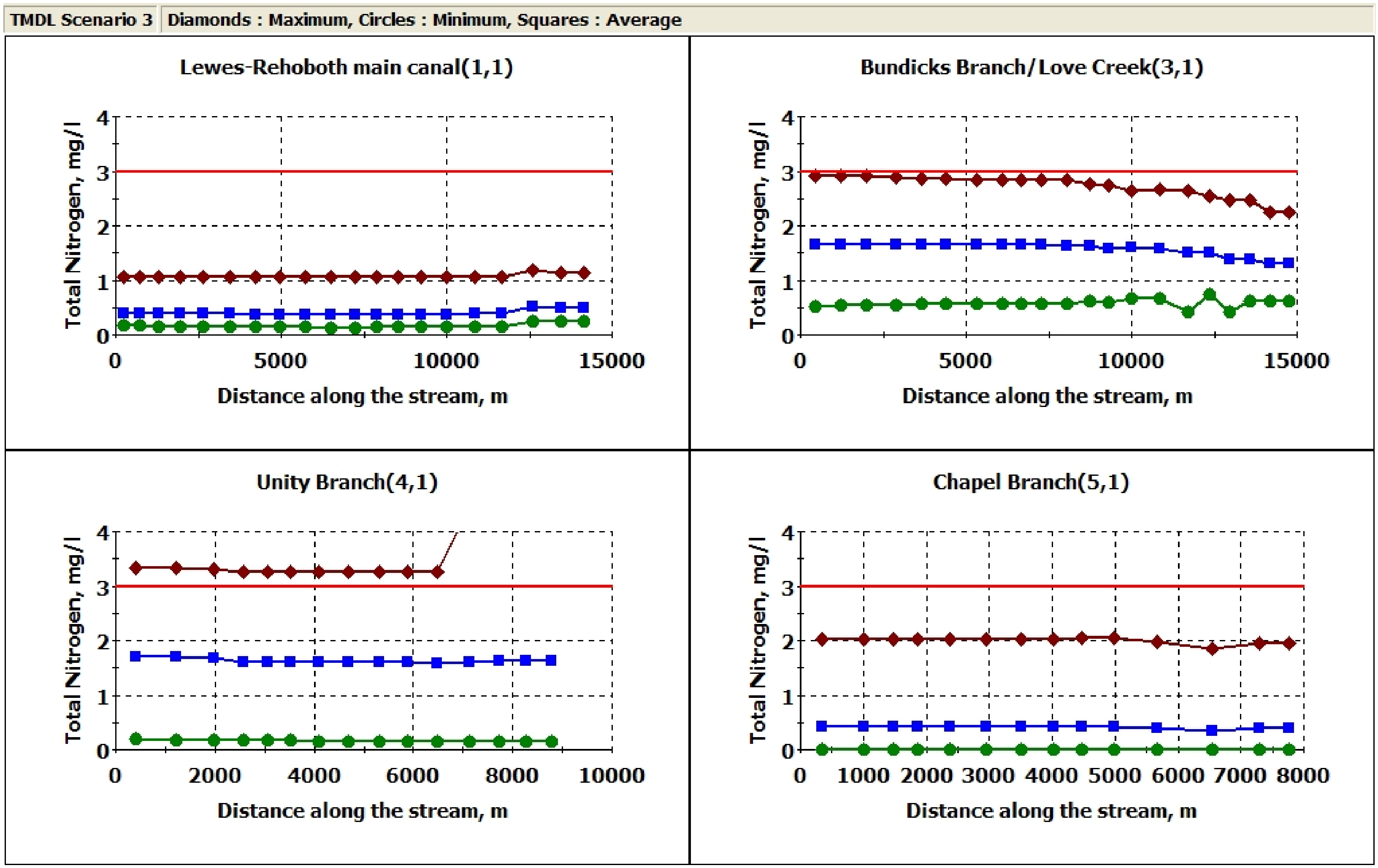


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

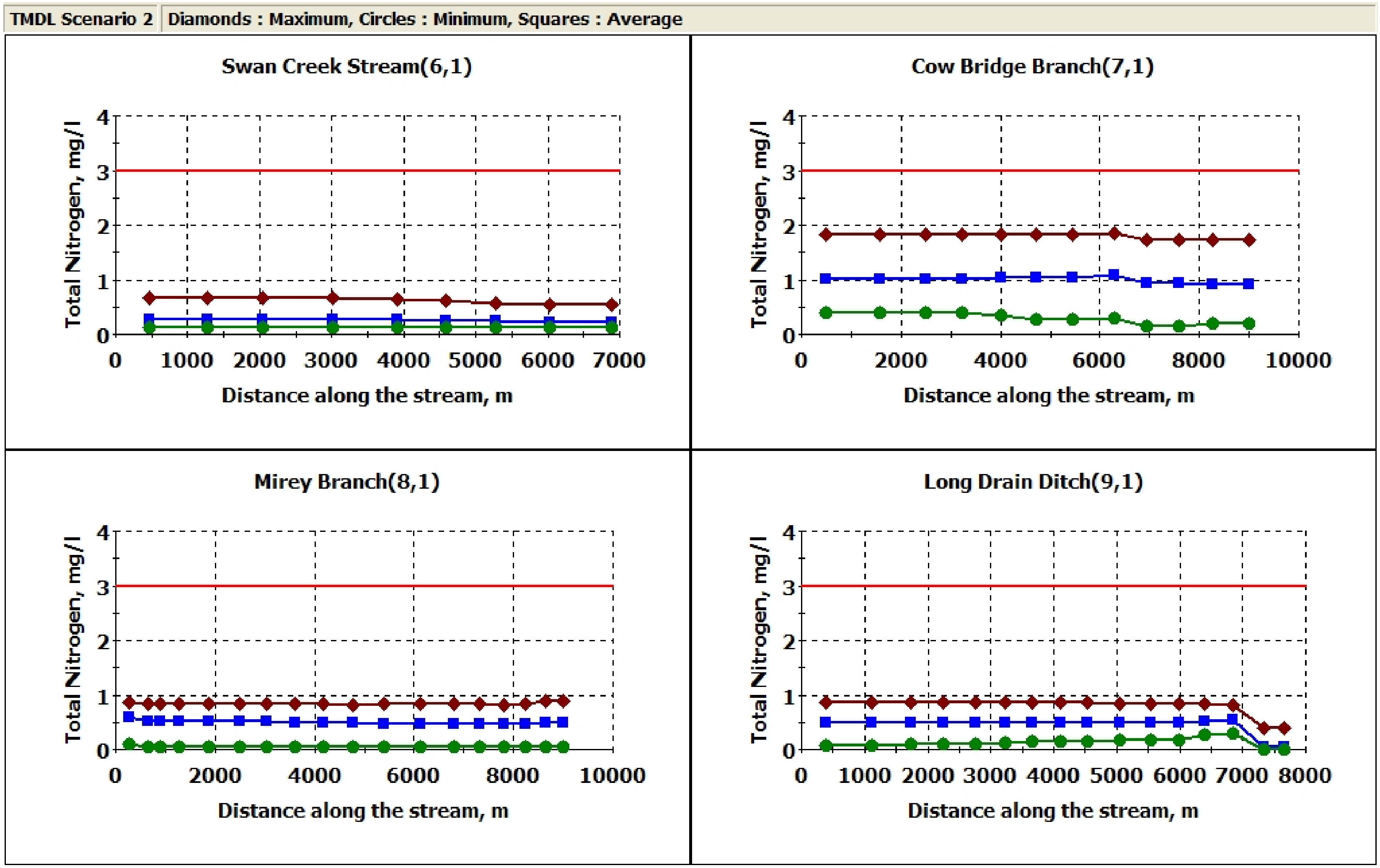


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

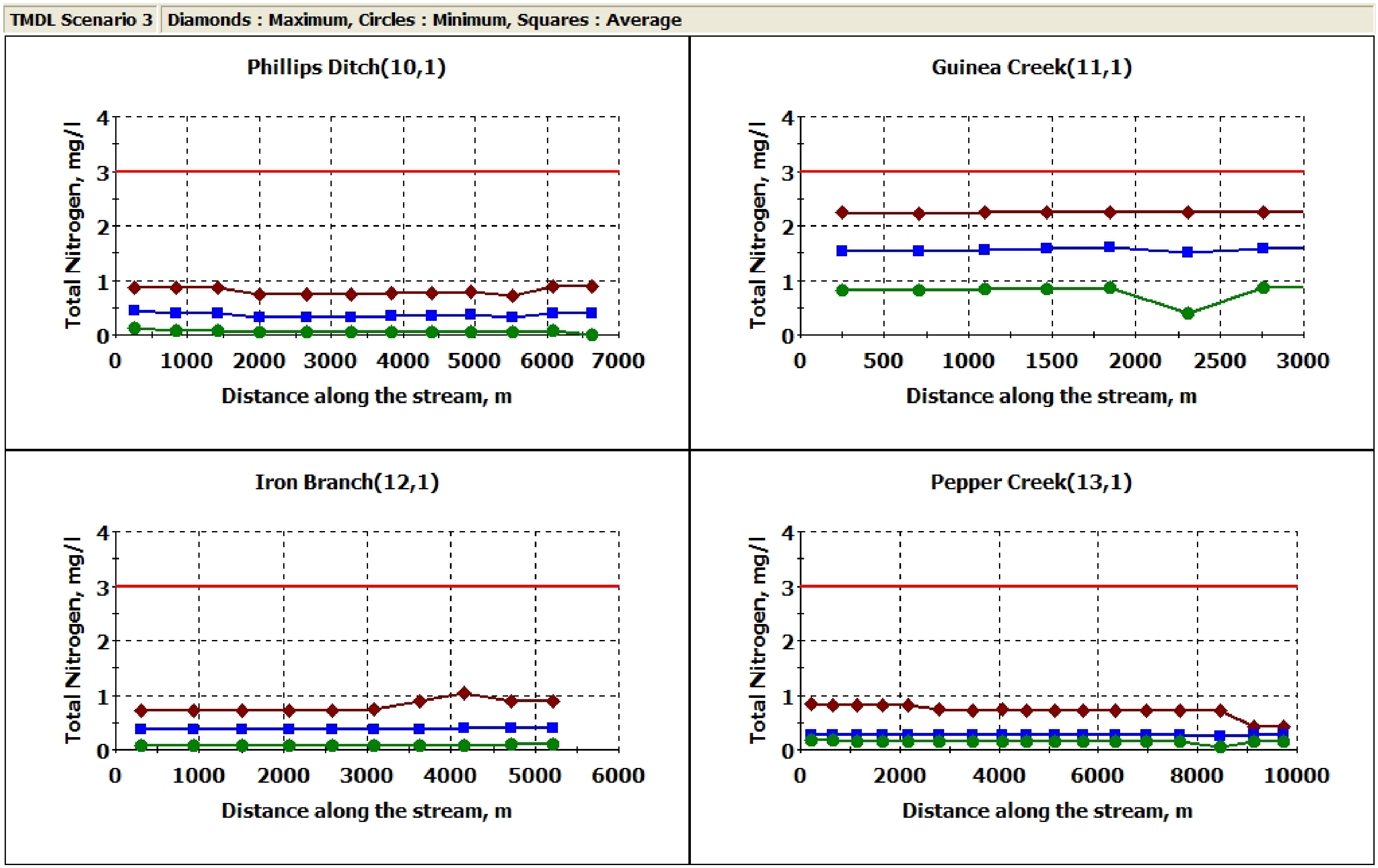


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

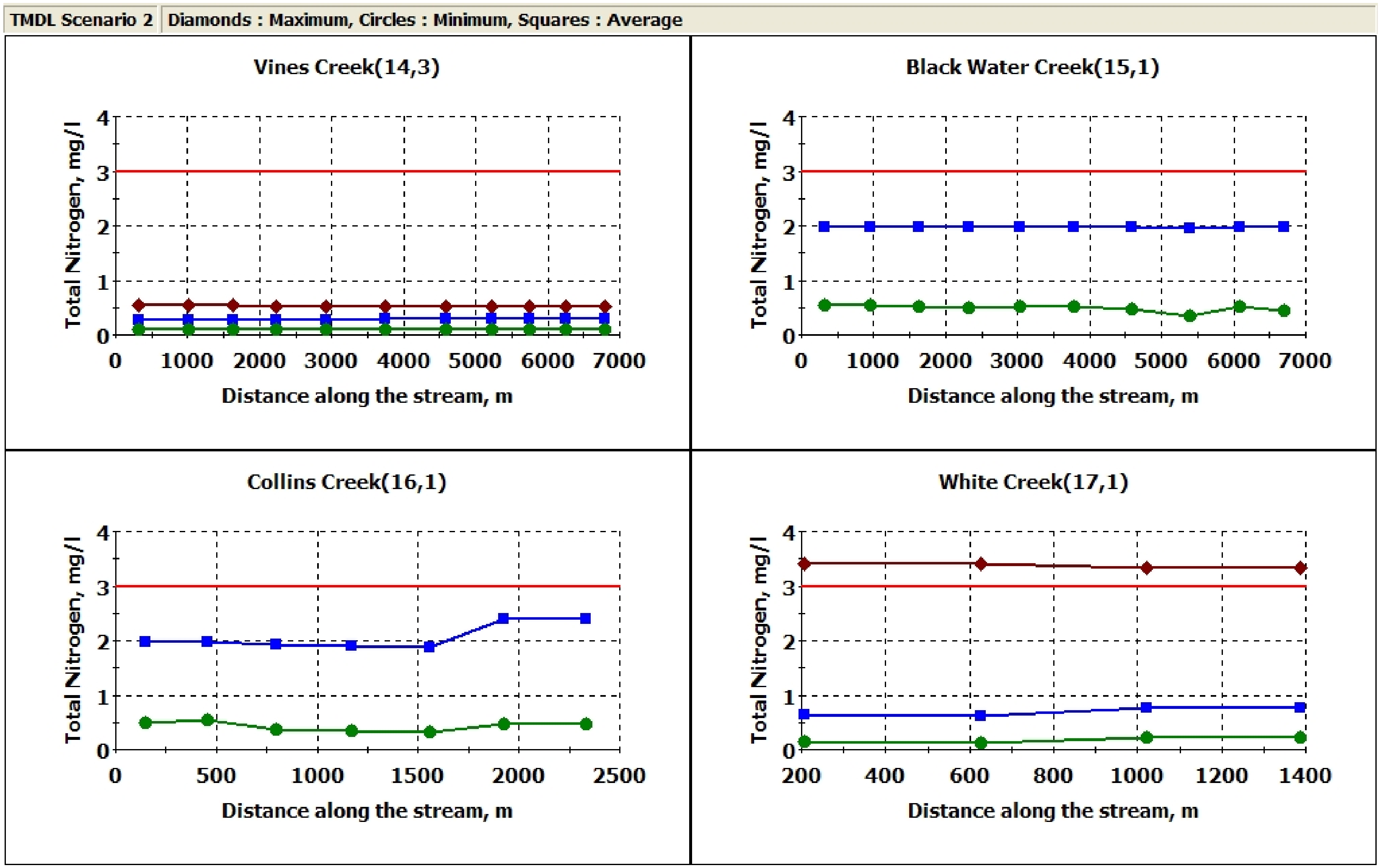


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

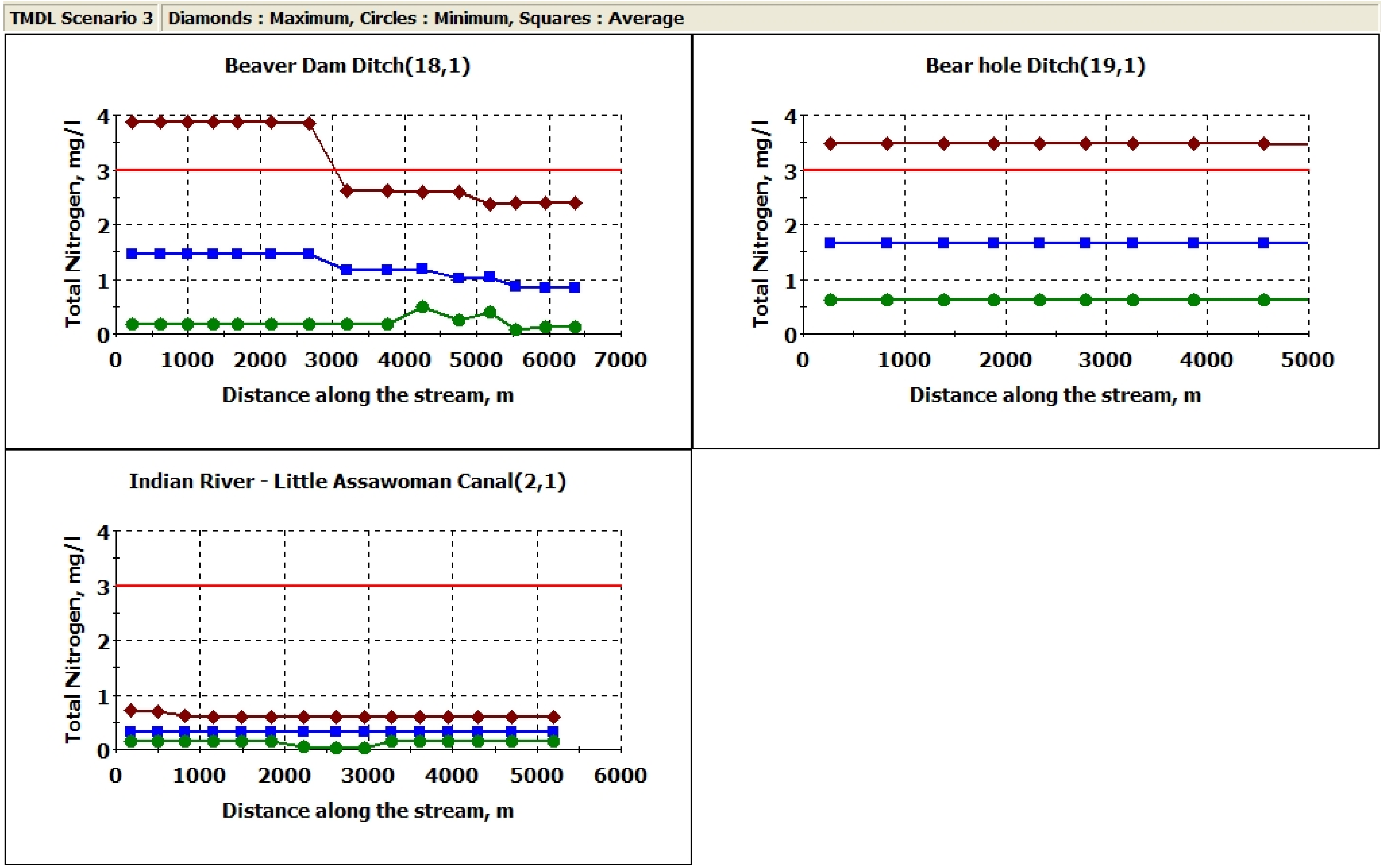
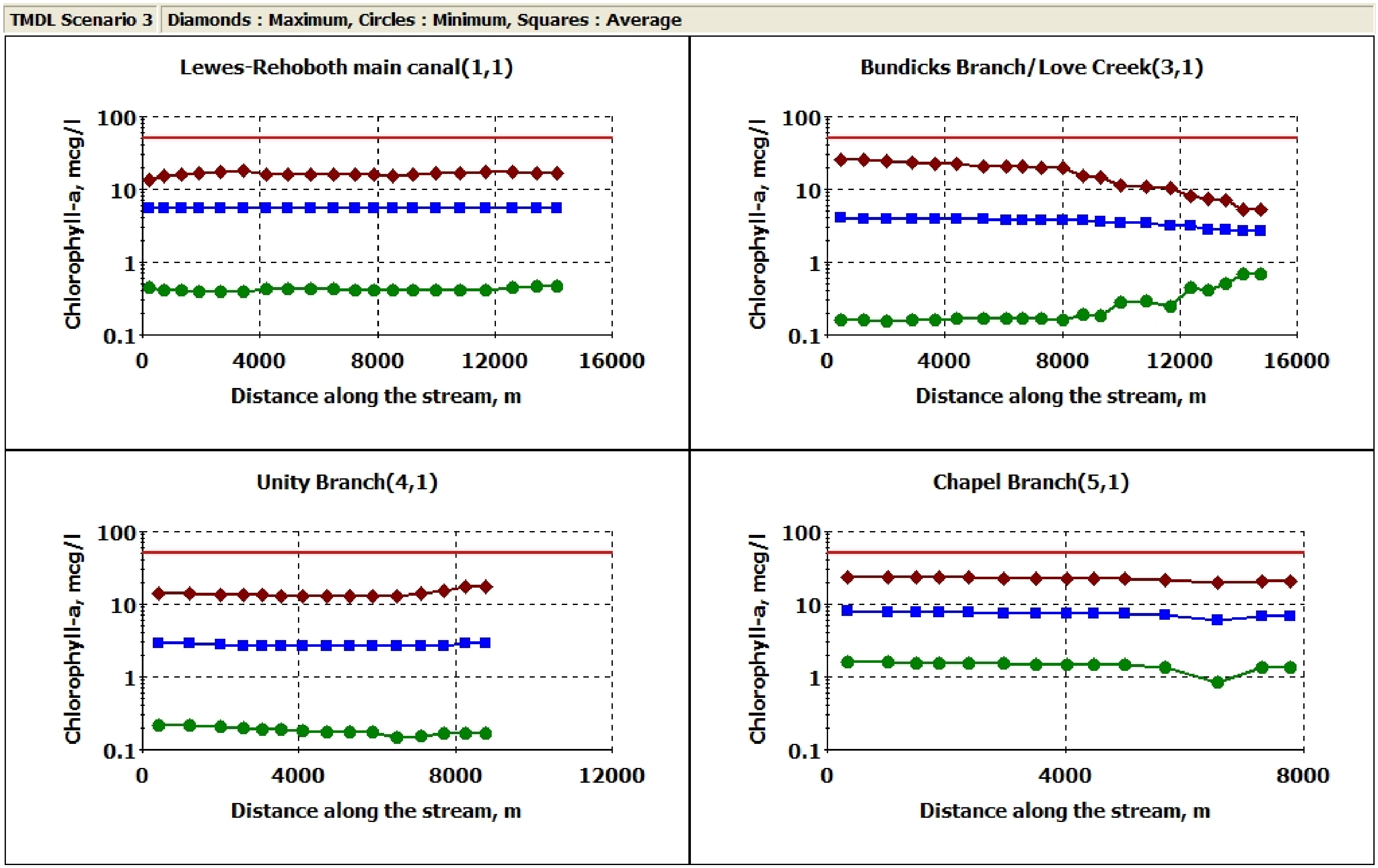


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)



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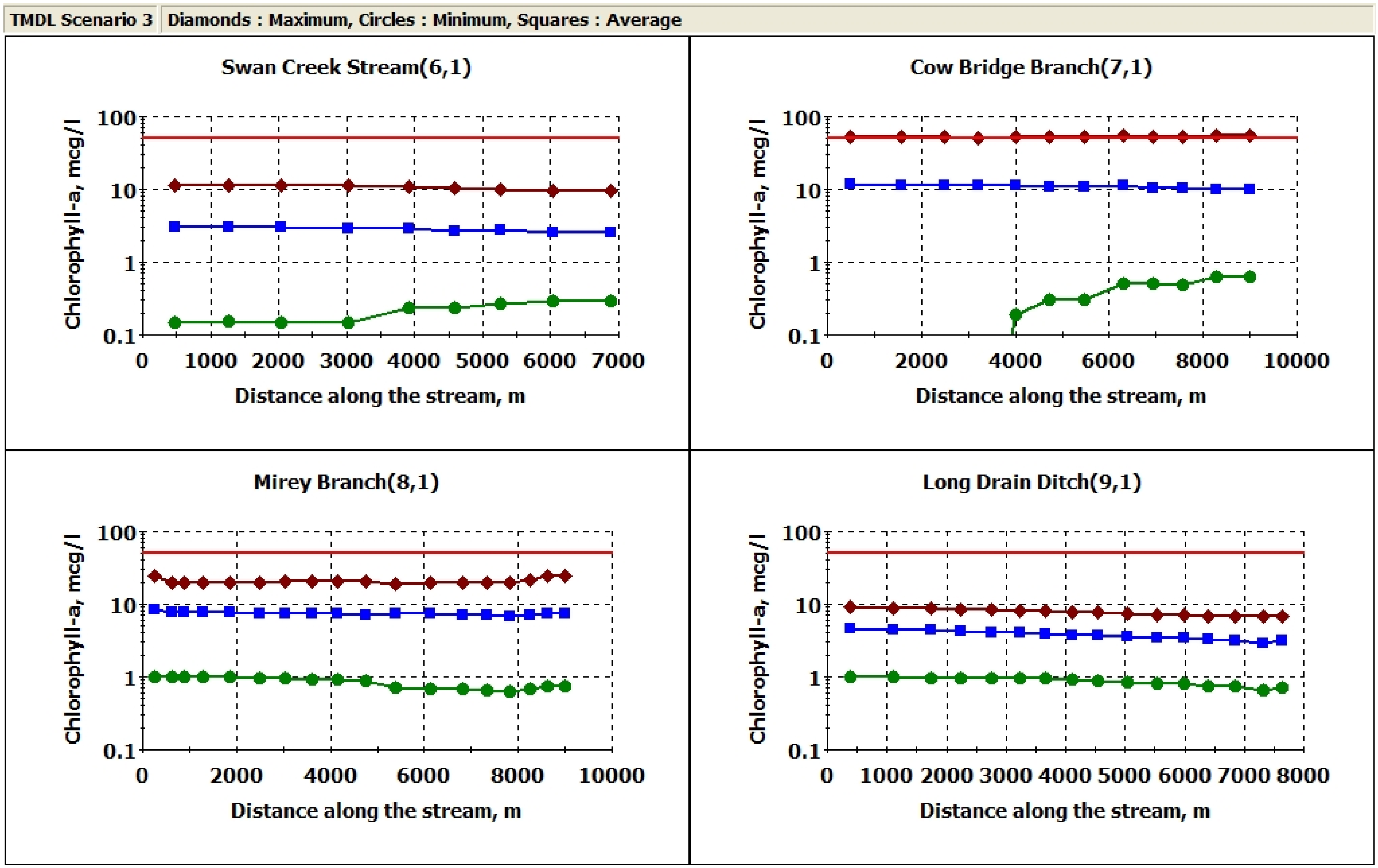

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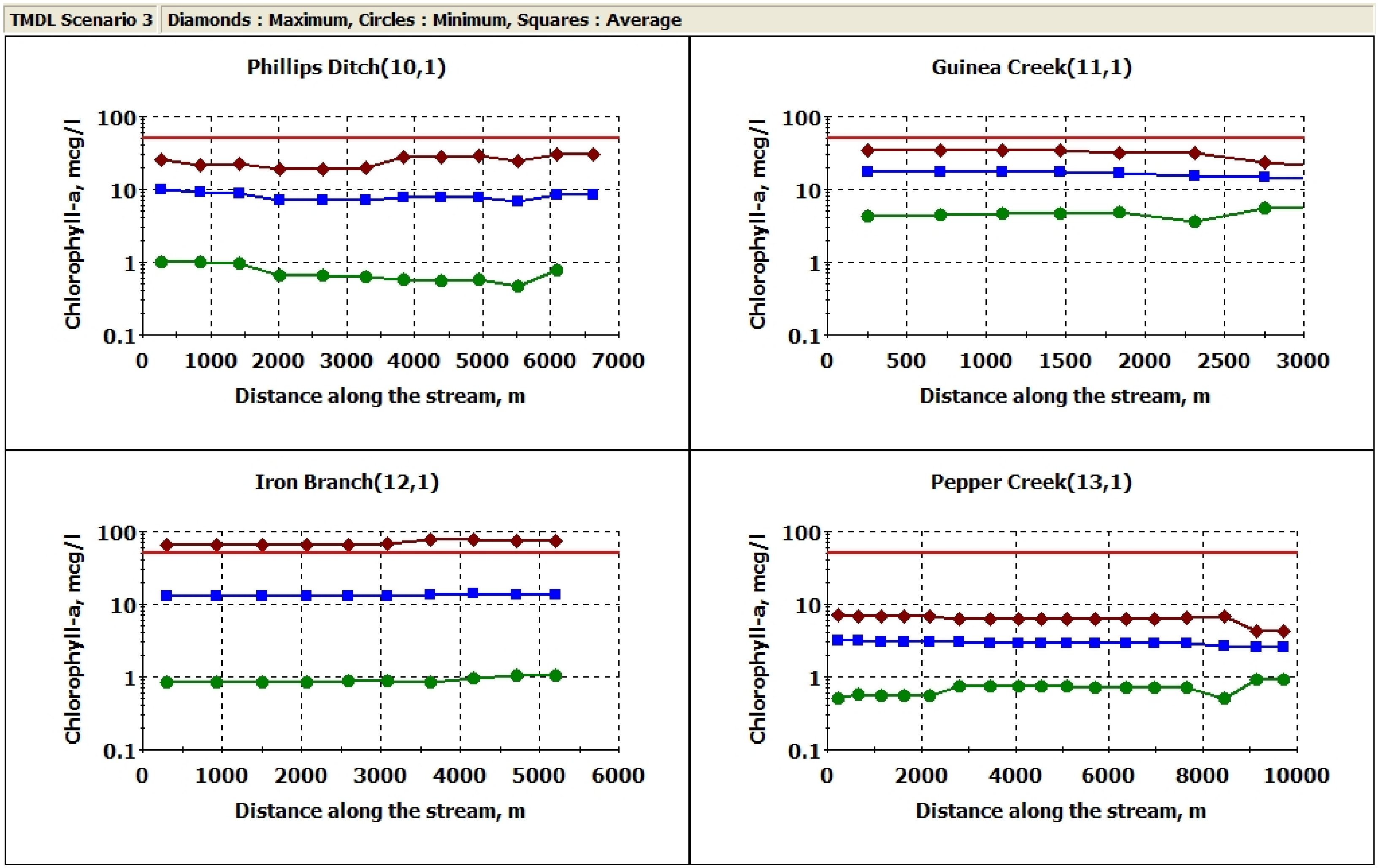


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

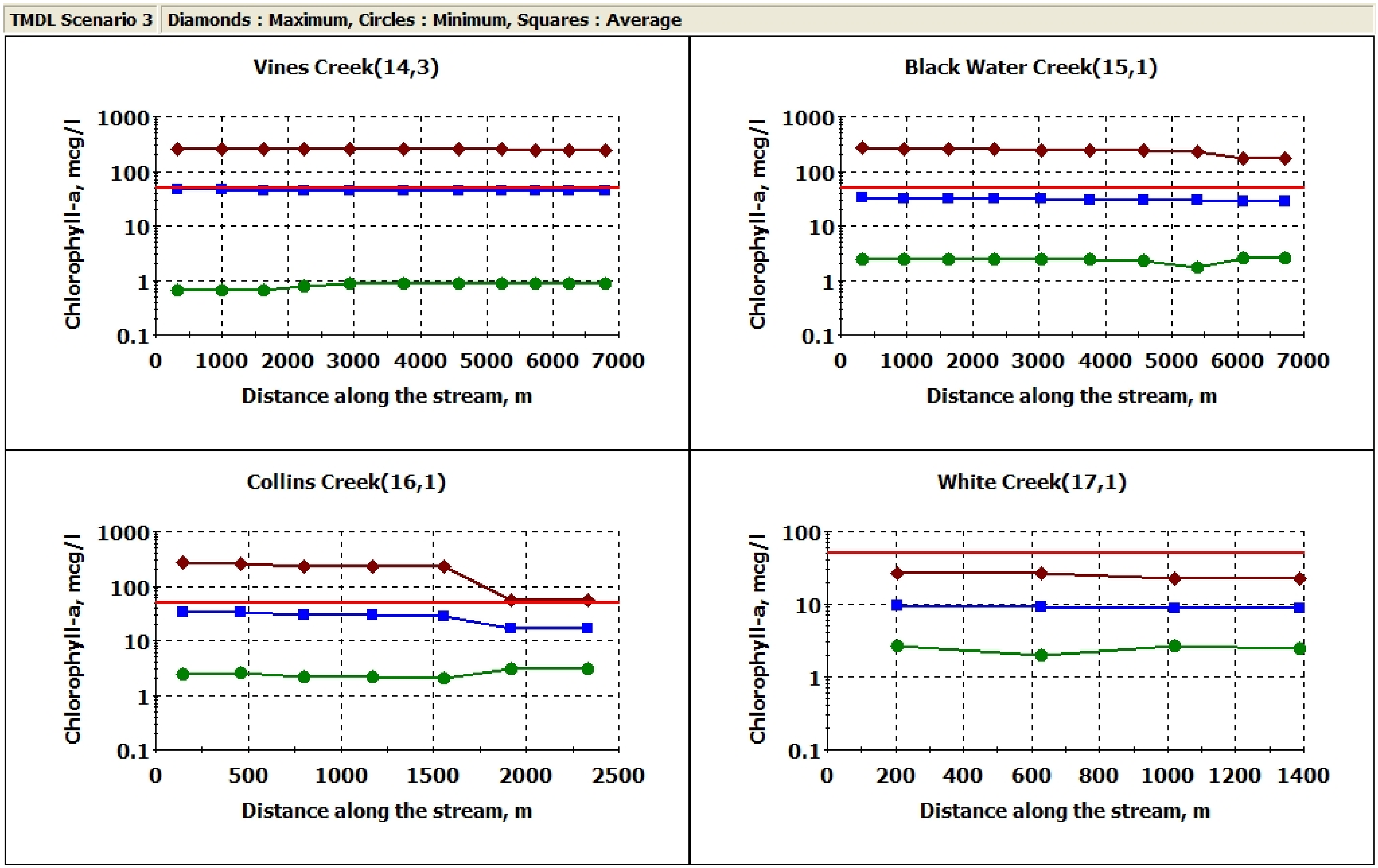


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

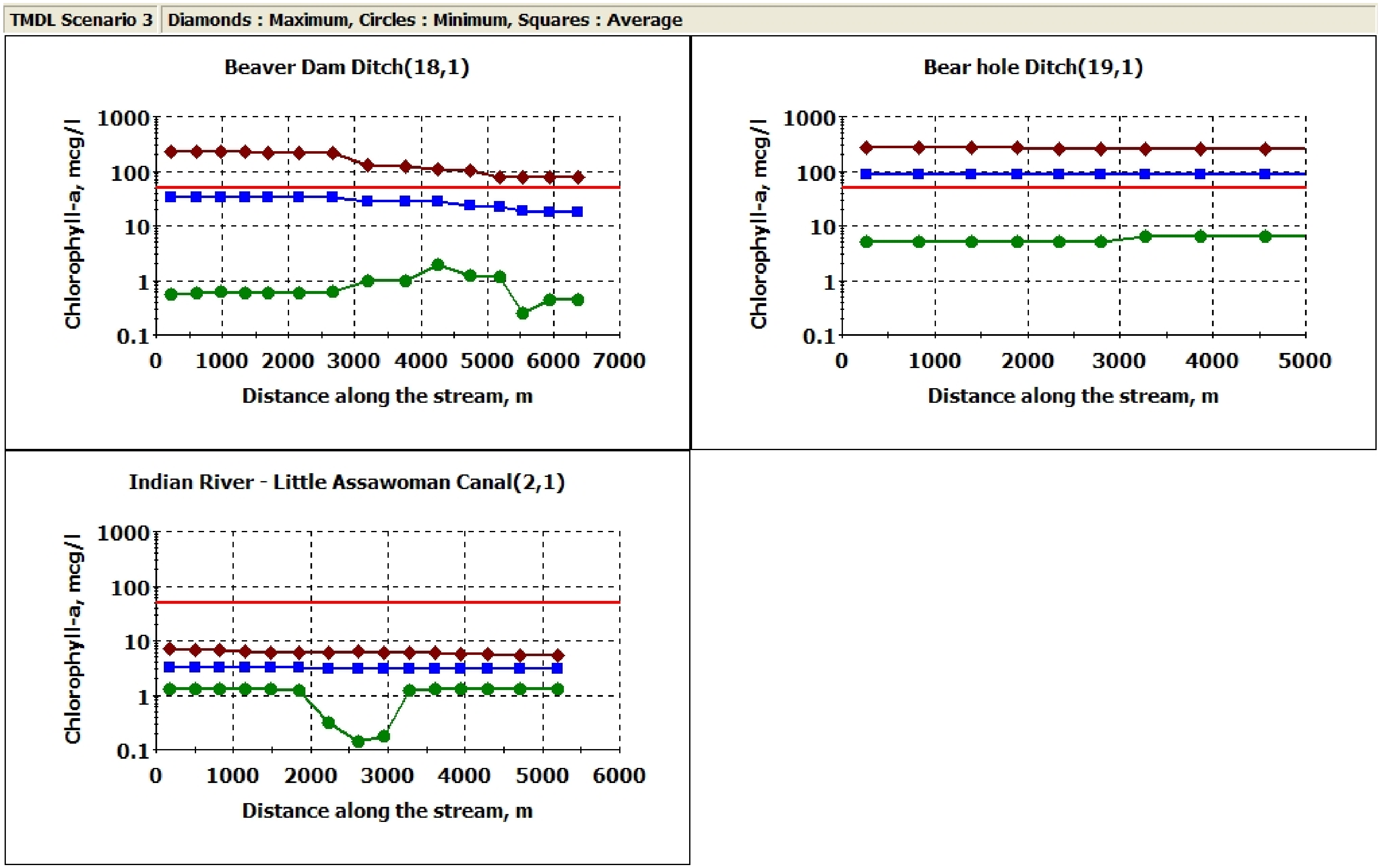


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

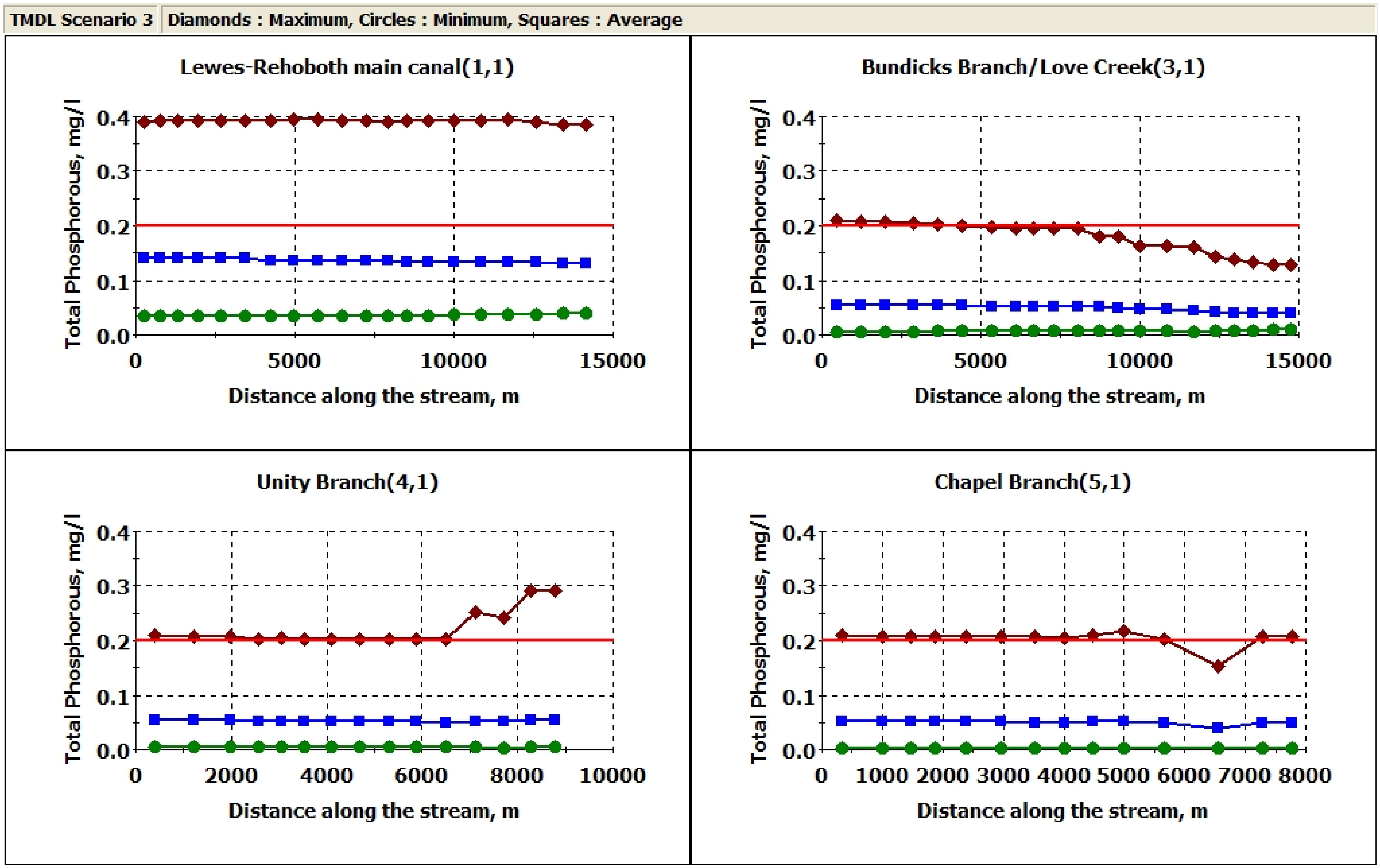


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

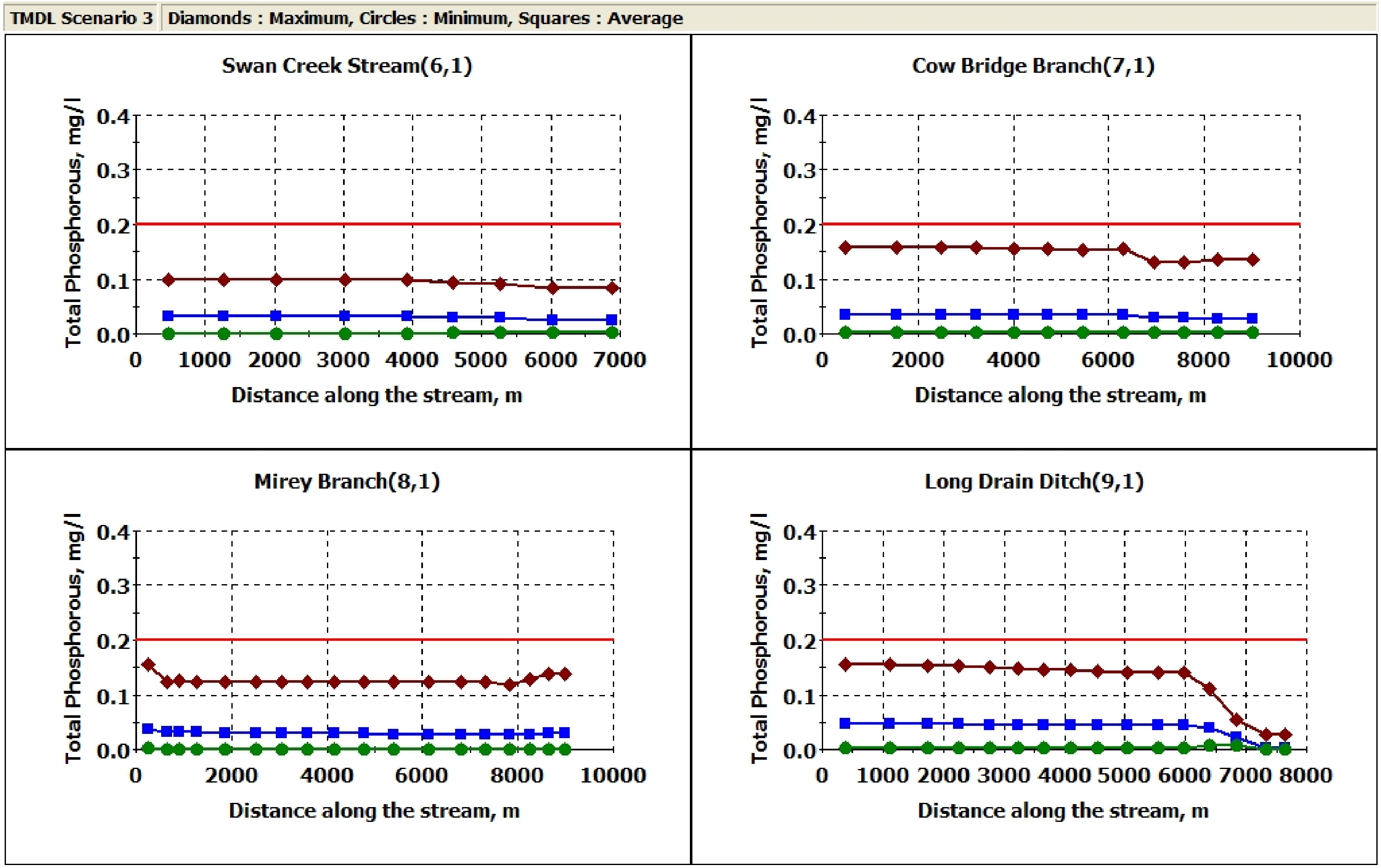


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

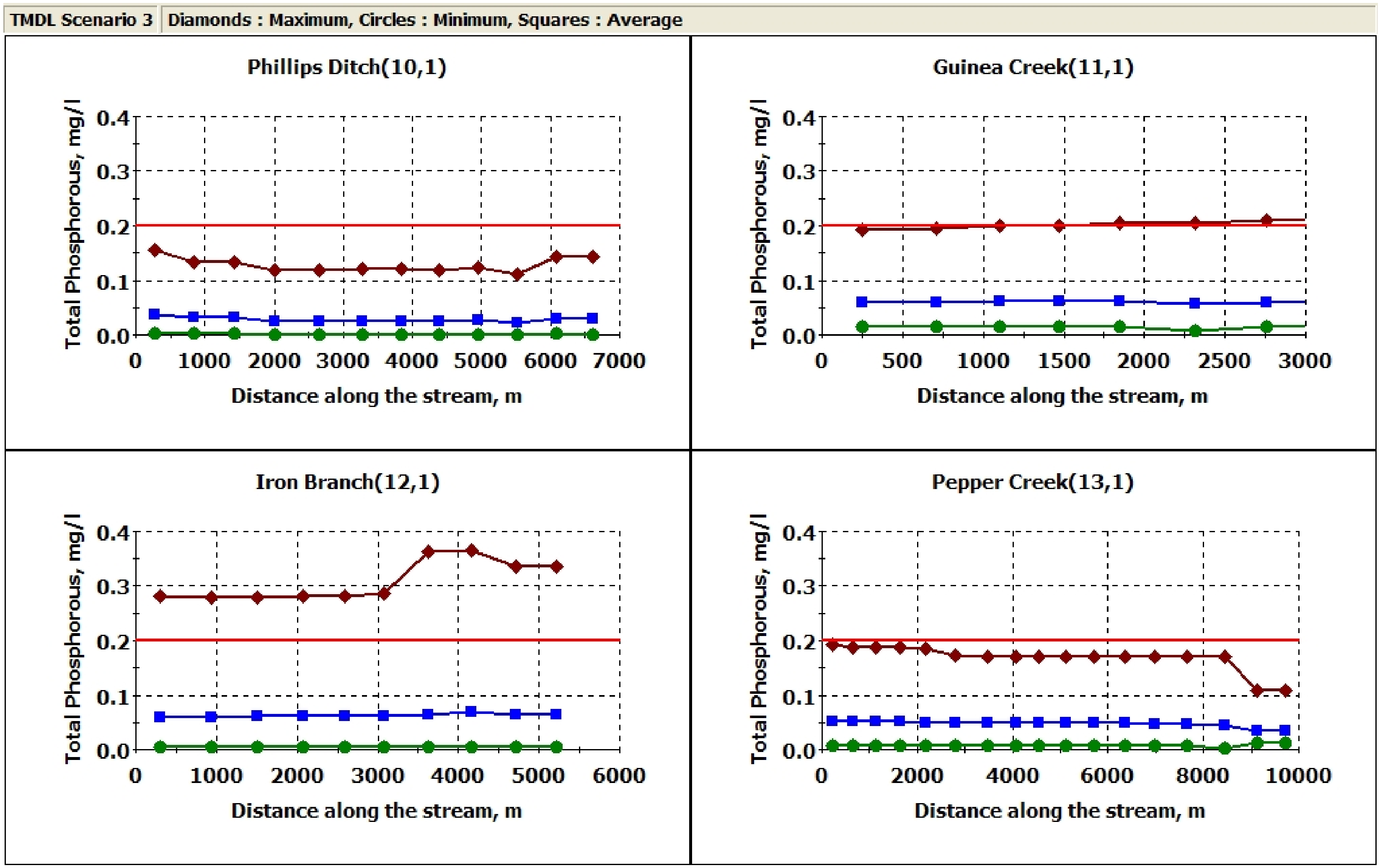


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

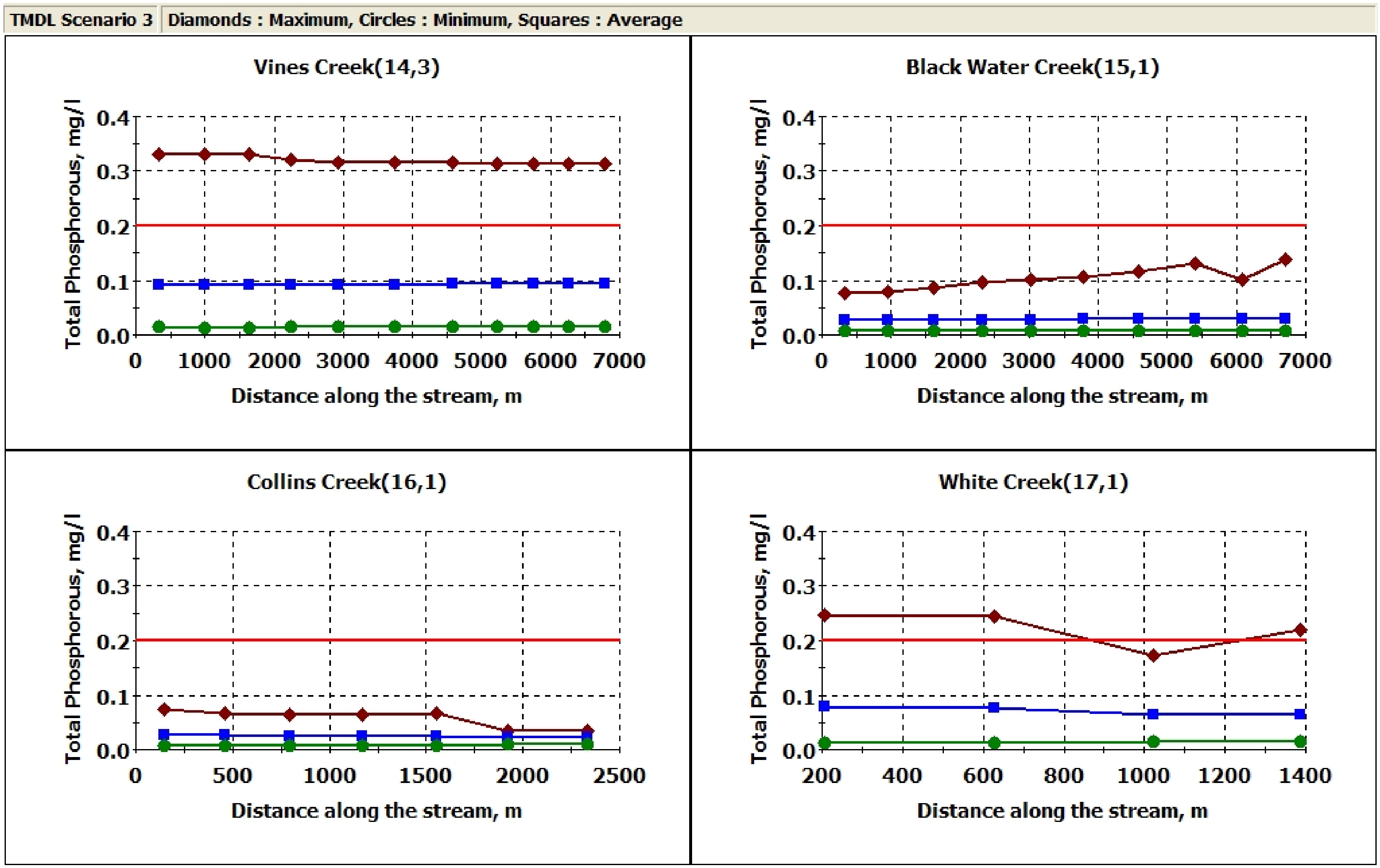


Figure 3-7. Results of Scenario 3 – Summertime Averages for Streams (continued)

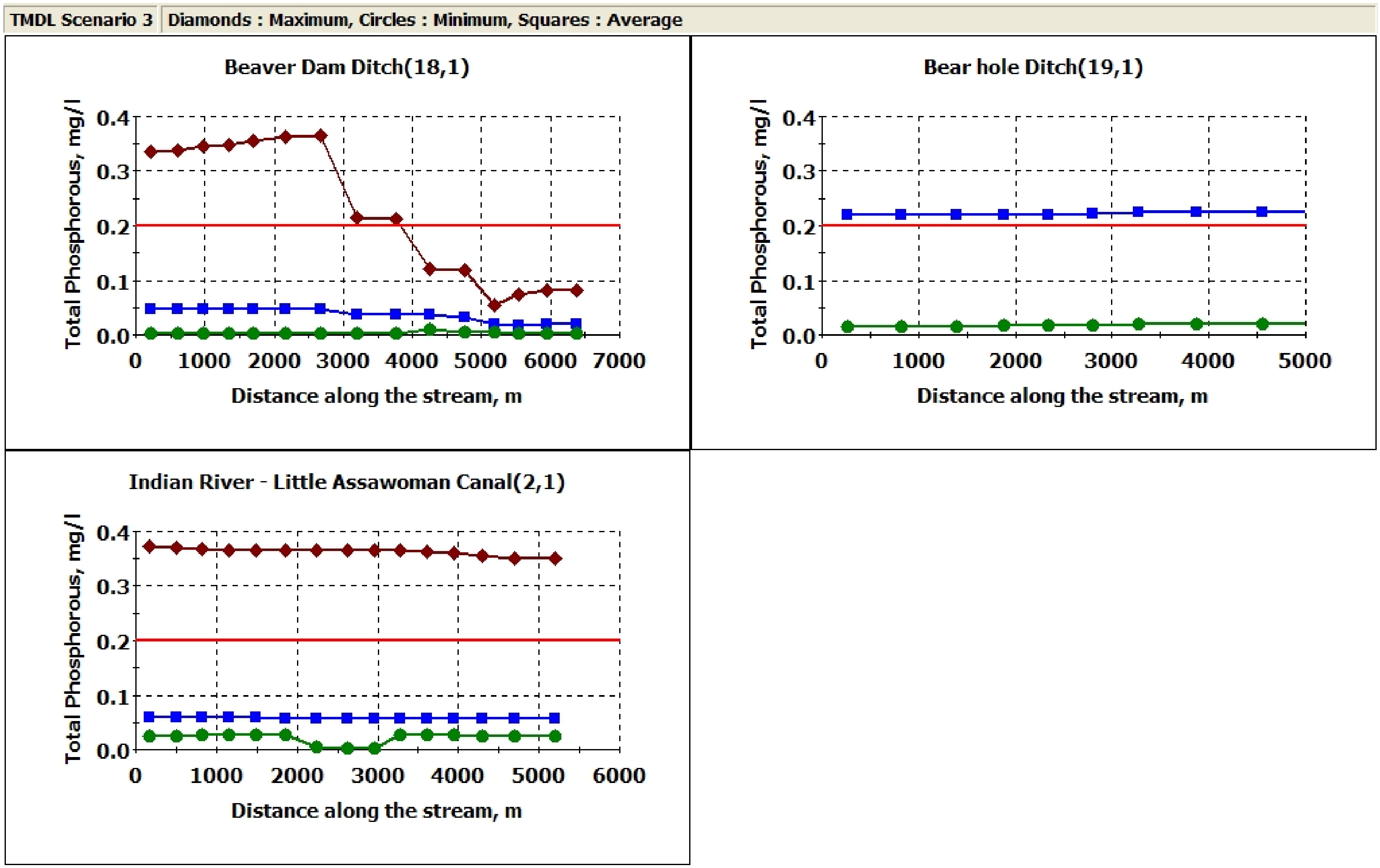
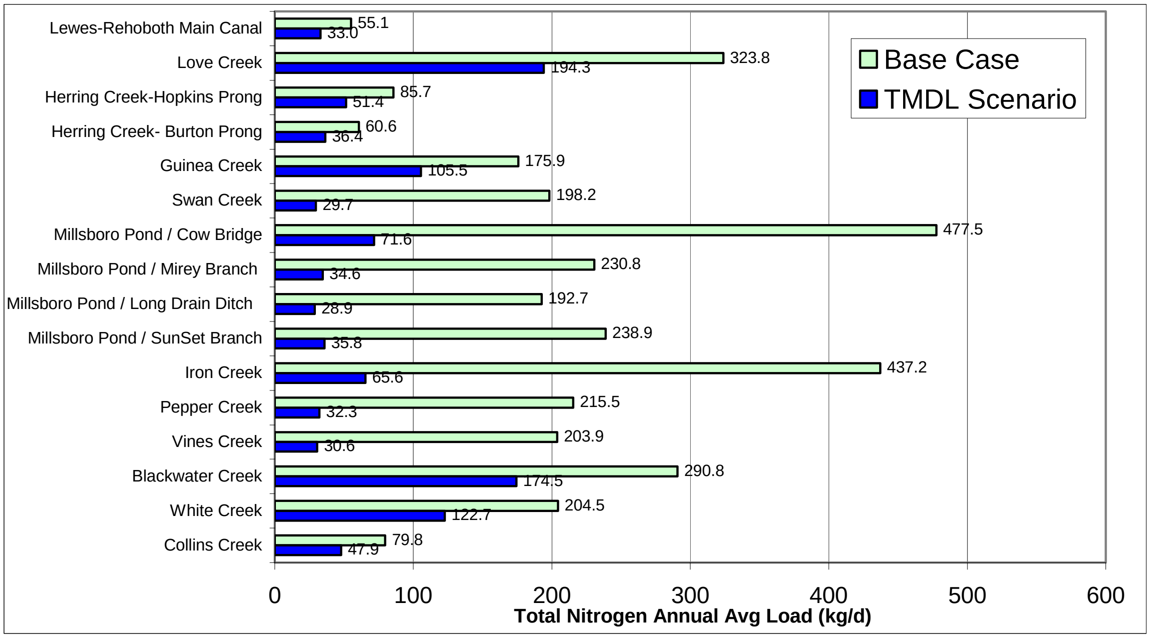
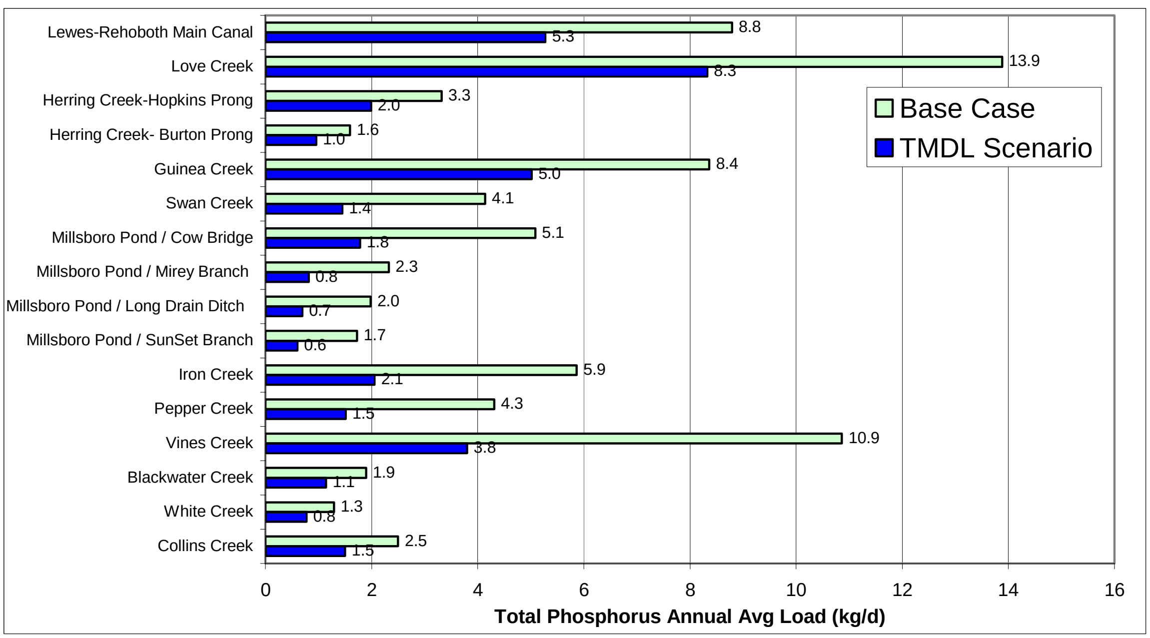


Figure 3-8. TMDL Values for Indian River and Rehoboth Bay Drainage Areas



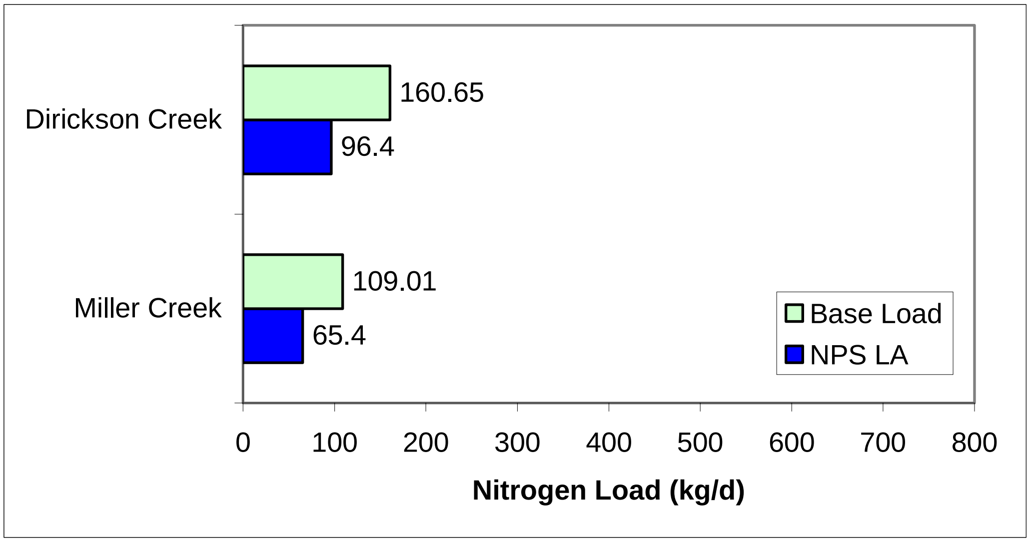


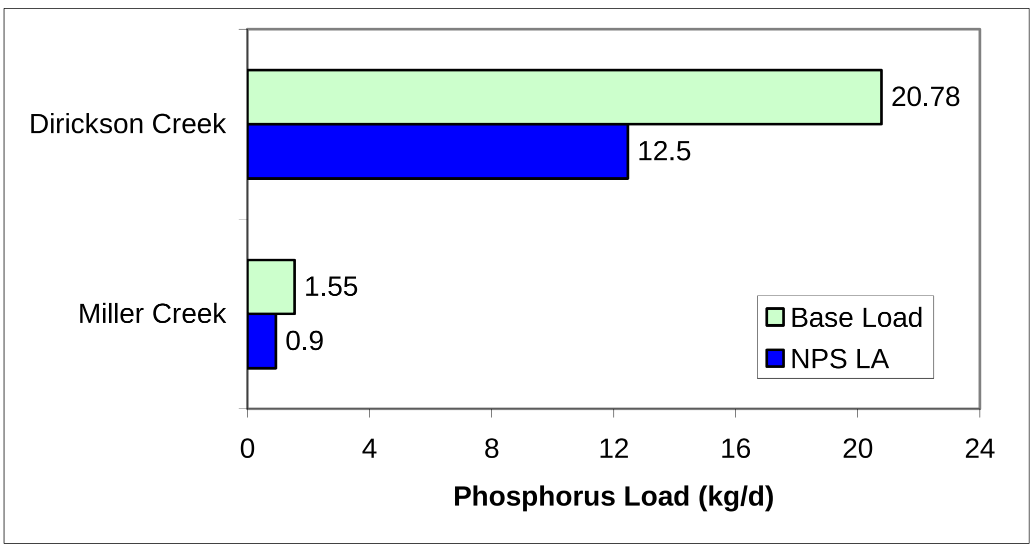
3.4.3 Establishment of the TMDL for Little Assawoman Bay

Based upon the application of the load reductions described in Section 1.3 upon the Little Assawoman drainage area, TMDLs for this area have been established. These are described for nitrogen and phosphorus in Figure 3-9. TMDLs are listed for the two main tributaries to Little Assawoman Bay: Dirickson Creek and Miller Creek. The nitrogen TMDLs are 96.4 kg/d and 65.4 kg/d for Dirickson Creek and Miller Creek respectively. For phosphorus TMDLs, the values are 12.5 kg/d and 0.9 kg/d for Dirickson Creek and

Miller Creek respectively. There are no point sources in Little Assawoman Bay requiring a TMDL.

Figure 3-9. Load Allocations for Little Assawoman Bay





3.4.4 Summertime Critical Loads

Once the TMDLs have been implemented, there will most likely be particular attention in future analysis upon the effectiveness of the load reduction management plans during the summertime critical time period. The TMDLs are based conservatively using the annual average loads forecast by the model after TMDL implementation. The summertime nonpoint source nitrogen loads predicted in the model are 154% higher than the annual average load, though the summertime phosphorus load was 76% less than the annual average. However, throughout the year, all water quality standards and targets are predicted to be met.

The summertime loads estimated in the TMDL Scenario are provided in Table 3-6.

Table 3-6. TMDL Scenario Summertime Nutrient Loads

TMDL Scenario **Receiving Body**	Stream Branch	**Total Nitrogen** **Summertime Load (kg/d)**	**Annual Avg Load (kg/d)**	Total Phosphorus **Summertime Load (kg/d)**	**Annual Avg Load (kg/d)**
Rehoboth Bay	Lewes-Rehoboth Main Canal	34.5	33.0	3.9	5.3
	Love Creek	183.3	194.3	2.0	8.3
	Herring Creek-Hopkins Prong	51.1	51.4	1.6	2.0
	Herring Creek- Burton Prong	24.6	36.4	0.8	1.0
	Guinea Creek	111.2	105.5	1.5	5.0
Indian River and Bay	Swan Creek	113.1	29.7	2.4	1.4
	Millsboro Pond / Cow Bridge	254.0	71.6	3.3	1.8
	Millsboro Pond / Mirey Branch	118.7	34.6	1.7	0.8
	Millsboro Pond / Long Drain Ditch	99.2	28.9	1.4	0.7
	Millsboro Pond / Sunset Branch	123.0	35.8	1.1	0.6
	Iron Creek	194.1	65.6	3.1	2.1
	Pepper Creek	90.5	32.3	2.5	1.5
	Vines Creek	99.5	30.6	3.9	3.8
	Blackwater Creek	158.5	174.5	0.9	1.1
	White Creek	111.5	122.7	0.6	0.8
	Collins Creek	28.8	47.9	1.0	1.5
Little Assawoman Bay	Miller Creek	40.7	65.4	0.6	0.9
	Dirickson Creek	104.0	96.4	6.5	12.5
TOTAL		**1940.3**	**1256.7**	**38.8**	**51.0**

Implementation of Proposed TMDLs for the Little Assawoman Bay

The Delaware DNREC will implement requirements of the proposed TMDLs for the Little Assawoman Bay through the development of a Pollution Control Strategy. The Strategy will be developed by DNREC in concert with the Inland Bays Tributary Action Team, other stakeholders, and the public.

The Inland Bays Tributary Action Team is currently working on development of a PCS for the Indian River, Indian River Bay, and Rehoboth Bay Watersheds. The TMDL regulation for these watersheds was adopted in December 1998. The Team is using the year 1990 as the base-line for designing the Pollution Control Strategy. Since the year 1990 is already being considered as the base-line for a major portion of the Inland Bays Watershed, it is recommended that the same base-line period be used for PCS development for the remaining parts of the watershed (including the Little Assawoman Bay). Using the same base-line period not only simplifies the PCS development process, it will make it more equitable for affected parties. A simple and equitable PCS is more likely to be endorsed by the public and be fully implemented. On the other hand, considering different base-line periods for different regions of the Inland Bays Watershed will confuse the public and may impede implementation of the TMDLs and PCS.

This practical concern is the most important justification for considering a single base-line (1990 in this case) for the entire Inland Bays Watershed, including the Little Assawoman Bay. However, a technical justification can also be found to support the use of the year 1990 as the base-line for designing a PCS for the Little Assawoman Bay. Results of the TMDL analysis included in this report show that, based on GEMSS model results, nonpoint source nitrogen and phosphorous loads within the Little Assawoman Bay Watershed should be reduced each by 40% in order to meet applicable water quality standards in all surface waters of the watershed. The GEMSS model predicts future water quality conditions under the TMDL loading scenario based on extensive field data collected during 1998 through 2000. Since water quality of the Little Assawoman Bay has not changed significantly from 1990 to the 1998-2000 period, it is reasonable to conclude that the same magnitudes of nonpoint source nitrogen and phosphorous load reduction would have been necessary in order attain applicable water quality standards in 1990.

In conclusion, considering the practical and technical justifications presented above, it is recommended that, consistent with the PCS being developed for the Indian River, Indian River Bay and Rehoboth Bay Watersheds, the year 1990 should be considered as the base-line period for developing a Pollution Control Strategy for the Little Assawoman Bay Watershed.

3.4.5 Discussion of the Regulatory Requirements for TMDLs

Eight requirements are mandated by federal regulations 40 CFR Section 130 for establishment of TMDLs. These are:

1. the TMDLs must be designed to achieve applicable water quality standards;
2. the TMDLs must include a total allowable load as well as individual waste load allocations for point sources and load allocations for nonpoint sources;
3. the TMDLs must consider the impact of background pollutants;
4. the TMDLs must consider critical environmental conditions;
5. the TMDLs must consider seasonal variations;
6. the TMDLs must include a margin of safety;
7. the TMDLs must have been subject to public participation; and

8. there should be a reasonable assurance that the TMDLs can be met.

The TMDL establishment for the Inland Bays have met these eight requirements, and will be described in below:

1. ***The TMDLs must be designed to achieve applicable water quality standard.***
   Section 1.2 describes the water quality standards for DO, nitrogen, and phosphorus in the Delaware Inland Bays. The criteria for DO are daily average of 5.0 mg/L (tidal water) and 5.5 mg/L (fresh water). For total nitrogen, the target values are daily maximums of 1.0 mg/L (tidal water) and 3.0 mg/L (fresh water). Total phosphorus target values are daily maximums of 0.1 mg/L (tidal water) and 0.2 mg/L (fresh water). In tidal waters, there are dissolved inorganic nitrogen and phosphorus criteria of 0.14 mg/L and 0.01 mg/L respectively. The target value of 20 µg/L (tidal water) and 50 µg/L (fresh water) for chlorophyll-*a* was listed as well.

   The results of the TMDL Scenario modeling indicate that these criteria and target values were met in all waters of the Inland Bays. Therefore, it can be concluded that the proposed TMDL meets the applicable water quality criteria and target values.

2. ***The TMDLs must include a total allowable load as well as individual waste load allocations for point sources and load allocations for nonpoint sources.***
   The total allowable loads have been calculated, as presented in Table 3-4. All individual point source WLA have been set to 100% removal of N and P from discharges. Load allocations for nonpoint source are described in Section 3-1.

3. ***The TMDLs must consider the impact of background pollutants.***
   The impact of background pollutants is considered via utilization of a comprehensive water quality database. This database (described in Section 3.1) includes extensive coverage both spatially and temporally across the bays and the surrounding tributaries of various dissolved and particulate forms of nitrogen and phosphorus, DO, temperature, chlorophyll *a*, salinity, pH, biological oxygen demand (BOD), and total organic carbon (TOC). Measurements at the ocean boundaries were used to establish the background concentrations entering the system due to tidal flushing. Measured values of sediment nutrient and oxygen demand fluxes were incorporated into the model. In areas where the HSPF model's nonpoint source estimates applied, calculations were made based upon watershed-specific knowledge of livestock populations and manure per land-use categories, method and schedules of organic and mineral fertilizer applications, planting and harvesting dates, and atmospheric depositions of nutrients (Gutiérrez-Magness and Raffensperger, 2003).

4. ***The TMDLs must consider critical environmental conditions.***
   The TMDL Scenario was run for summertime conditions to reflect the time of the year when DO conditions are typically at their lowest and chlorophyll is at its highest due to the combination of the ambient temperatures with available nutrients. As described in Section 3-2, there was no single critical year. Therefore the summertime three-year average of 1998-2000 was used for the TMDL analysis.

5. ***The TMDLs must consider seasonal variations.***

Modeling is performed for three consecutive years from 1998 through 2000. Although the focus was on the critical time period of the summertime, the model was calibrated from January to December in 1999, and verified from January to December in 2000. Therefore, seasonal variations were considered in the modeling.

6. ***The TMDLs must include a margin of safety.***
   Section 303(d)(1)(C) of the Clean Water Act describes the requirements of States to develop TMDLs for waters with impaired water quality. This section also recommends inclusion of a margin of safety to account for uncertainty related to the field data interpretation and modeling for the establishment of TMDLs. The reductions in current loads used for the TMDL analysis were chosen not to simply meet standards and target values but to attain water quality above the standards and targets. The three-year summertime average concentrations (Figure 3-6 and Figure 3-7) indicate that all applicable water quality standards and target values will be met with a reasonable margin of certainty. Although an explicit margin of safety, in which there is a specific percentage of the assimilative capacity of the system targeted, was not used, EPA's technical guidance allows for an implicit margin of safety. An implicit margin of safety provides assurance of the model's predictions through use of conservative assumptions. The TMDL modeling performed utilized conservative assumptions such as analysis during critical summertime conditions under low flows and high temperatures, use of conservative reaction rates, pollutant loads, and other environmental conditions. Therefore, an implicit margin of safety has been considered for establishing the proposed Little Assawoman Bay TMDLs.

7. ***The TMDLs must have been subject to public participation.***
   The 1998 TMDLs was adopted following significant public participation process including public workshops and public hearing.

   This proposed TMDL has also been subject to public participation. The result of this analysis was presented to the Delaware Inland Bays Scientific and Technical Advisory Committee (STAC) on July 9, 2004 and to the Inland Bays Tributary Action Team on August 10, 2004. Additional pubic workshops and hearing is planned prior to formal adoption of the proposed TMDL Regulation.

8. ***There should be a reasonable assurance that the TMDLs for the Little Assawoman Bay and Tributaries and Ponds of the Inland Bays can be met.***
   The proposed TMDLs for the Little Assawoman Bay and Tributaries and Ponds of the Inland Bays require systematic elimination of all point sources within the watershed and significant reduction of nonpoint source nutrient loads.

   The DNREC is currently working with the Inland Bays Tributary Action Team (TAT) to develop and finalize a Pollution Control Strategy for implementing the requirements of the 1998 TMDLs for the Indian River, Indian River Bay, and Rehoboth Bay. The TAT will be asked to assist the Department in expanding the Pollution Control Strategy to include the Little Assawoman Bay and other areas that were not part of the 1998 TMDL.

It is noteworthy to mention that the Department has already made significant progress in implementing the requirements of the 1998 TMDL Regulation by eliminating several point source discharges and reducing nonpoint source loads. Delaware DNREC is committed to continue this path forward and implement requirements of the proposed TMDLs for the Little Assawoman Bay and Tributaries and Ponds of the Inland Bays.

4.0 CONCLUSIONS

The effectiveness of the TMDL reductions prescribed in the 1998 TMDL Report were examined by predicting the resulting water quality improvements within the rivers, bays, streams, and ponds of the Inland Bays upon attainment of the recommended point and nonpoint source load reductions. Examinations were made into changes in concentration of DO, nitrogen, phosphorus, and chlorophyll *a* compared to the State's water quality criteria or target values.

The TMDL scenario was run with several assumptions used to make realistic predictions of future conditions after the prescribed TMDL reductions have been established. All necessary water quality objectives have been met in this scenario. TMDLs for the Little Assawoman Bay drainage area have been established. The efficacy of the 1998 TMDL has been confirmed. Therefore, it has been determined that the prescribed TMDLs are sufficient to attain the necessary water quality objectives within the Delaware Inland Bays.

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